State of California
The Resources Agency
Department of Water Resources
Northern District

LIMNOLOGICAL INVESTIGATION OF MORRIS RESERVOIR

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Gordon K. Van Vleck
Secretary for Resources
The Resources Agency

George Deukmejian
Governor
State of California

David N. Kennedy
Director
Department of Water Resources

FOREWORD

This report presents the findings of a limnological investigation of Morris Reservoir cooperatively conducted between the Department of Water Resources and City of Willits. The report discusses loss of storage capacity in the reservoir due to sedimentation, and organic and inorganic parameters that contribute to the poor quality of potable water from the reservoir.

The study concludes that nutrient stimulation of phytoplankton leads to degradation of water quality in Morris Reservoir. Nearly half of the phytoplankton genera occurring in Morris Reservoir are known to cause taste and odor problems in water supplies. Decomposition of phytoplankton depletes the hypolimnion of oxygen, resulting in further degradation of water quality through solubilization of metals and nutrients from the bottom sediments and formation of hydrogen sulfide.

Recommendations are included to manage the reservoir to enhance nutrient export and disrupt nutrient recycling for prevention of noxious growths of phytoplankton and subsequent water quality degradation.

Wayne S. Gentry, Chief
Northern District

State of California
GEORGE DEUKMEJIAN, Governor

The Resources Agency
GORDON K. VAN VLECK, Secretary for Resources

Department of Water Resources
DAVID N. KENNEDY, Director

JOHN P. CAFFREY
Deputy Director

ROBERT E. WHITING
Deputy Director

ROBERT G. POTTER
Deputy Director

SALLE S. JANTZ
Assistant Director

SUSAN N. WEBER
Chief Counsel

NORTHERN DISTRICT

Wayne S. Gentry . . . . . Chief
Philip J. Lorens . . . . . Chief, Water Management Branch
Robert A. Steel . . . . . Chief, Water Quality and Biology Section

Study supervision and report preparation by

Gerald L. Boles . . . . . Environmental Specialist IV

Responsibility for field activities and drafting by

Stephen M. Turek . . . . . Environmental Specialist II

Assistance provided by

David J. Bogener . . . . . Environmental Specialist II
Diane M. McGill . . . . . Executive Secretary
June M. Daniels . . . . . Office Technician
Clifford D. Maxwell . . . . . Senior Delineator

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ABSTRACT

Morris Reservoir provides potable water to the City of Willits. Complaints of tastes and odors from the water commonly occur during the summer. A limnological investigation of Morris Reservoir was conducted from April 1986 through June 1987 by the Department of Water Resources in cooperation with the City of Willits to determine causes of the water quality degradation.

Reservoir storage, originally 722 acre-feet, has been reduced to 623 acre-feet from sedimentation. Sediments have filled to within 1.2 feet of the lower outlet at the dam.

Warming temperatures beginning in the spring result in thermal stratification of the reservoir. Optimum nutrient and light conditions during the spring contribute to abundant phytoplankton growth, which eventually depletes phosphorus nutrients in the euphotic zone. Treatment at the lake surface with copper sulfate results in mass mortality of phytoplankton in the upper regions of the reservoir. Partial decomposition in the epilimnion of sinking phytoplankton liberates nutrients which stimulate increased production by algae unaffected by the copper sulfate which rapidly forms a non-toxic precipitate. Algae known to cause tastes and odors in water supply reservoirs dominate the phytoplankton community due to ability of some to use nitrogen from the atmosphere during nutrient limitation, and ineffective grazing by zooplankton.

Decomposition of organic materials in the hypolimnion during thermal stratification results in depletion of oxygen. Anaerobic decomposition of organic materials results in production of hydrogen sulfide. Anoxic conditions at the sediment-water interface allows dissolution of iron and manganese compounds containing phosphorus and other bound nutrients which migrate into the water. Iron readily forms an insoluble precipitate in the presence of hydrogen sulfide.

Cooling air temperatures in the fall result in thermal destratification. Wind-induced mixing of surface and bottom waters results in redistribution of nutrients, metals, and oxygen throughout the water column. Additional nutrients and metals are carried into the reservoir with turbid tributary inflow. Cool temperatures and low light from decreasing photoperiod and increased turbidity result in little phytoplankton production during the winter. Conditions again become optimum for algal growth in the spring.

Tastes and odors in potable water from Morris Reservoir have several causes. Thirteen of the 28 species of algae found in the reservoir, which includes all the dominant species, are known to cause tastes and odors in water supply reservoirs. Hydrogen sulfide produces a highly discernable odor. Manganese and iron, both of which produce adverse tastes in potable waters, were often at concentrations exceeding established criteria. The addition of copper sulfate to control phytoplankton growth actually produces a stimulatory effect by causing increased decomposition of algae and recycling of nutrients in the euphotic zone. Little decomposition of senescent algae normally occurs in the euphotic zone. Precipitation of sulfate from solubilized copper sulfate results in increased hydrogen sulfide production in the anoxic hypolimnion. The hydrogen sulfide decreases iron concentrations which would normally form

precipitates with phosphorus following aeration from destratification and mixing. Increased phosphorus concentrations allow increased phytoplankton production.

Management of nutrient sources is required to reduce phytoplankton production, which will in turn reduce oxygen consumption in the hypolimnion and solubilization of metals and nutrients in the sediments. Watershed management is recommended to reduce external sources of nutrients. Strategies to control nutrient and metals levels in the reservoir include export of turbid water from the bottom of the reservoir during the winter and oxygenation of the hypolimnion and nutrient precipitation from the epilimnion during thermal stratification.

INTRODUCTION

Domestic water for the City of Willits is provided by Morris Reservoir. Despite treatment at the City's Water Treatment Plant, objectionable tastes and odors of an earthy or musty nature often occur in the finished water during the sumer. Blooms of algal species associated with taste and odor problems in reservoirs occur during the summer and are treated with copper sulfate to control plant biomass. Low dissolved oxygen and high iron and manganese levels also occur in the deeper reservoir water (Kennedy/Jenks Engineers, 1985). In addition, insufficient water is stored in Morris Reservoir to meet municipal water demands during years of low precipitation.

The California Department of Water Resources (DWR), in cooperation with the City of Willits, initiated a limnological investigation of Morris Reservoir beginning in April of 1986, with field data collection continuing through June of 1987. The purposes of the investigation were to define the general limnology of Morris Reservoir, determine the loss of storage capacity due to sedimentation, identify the causes of the taste and odor problems, and present recommendations for effectively managing the quality of water.

STUDY AREA

Morris Reservoir is located approximately 4 miles southeast of the City of Willits in Section 33, Township 18N, Range 13W, Mount Diablo Base and Meridian (Figure 1). The 51.2-foot-high concrete arch dam, completed in 1927, has a crest length of 129 feet and a crest elevation of 1,542.2 feet. Two outlet levels are available for release of water to the Water Treatment Plant. The centerline of the 12-inch-diameter upper outlet pipe is located 16.6 feet below the crest, while the lower outlet level, composed of two 12-inch-diameter pipes, is located 41.3 feet below the crest. Storage capacity between the crest and the lower outlet has been estimated at 621 acre-feet (McCoy, 1979). Wooden 2.5-foot-high flashboards are used to increase storage to 722 acre-feet.

Morris Reservoir is located on Davis Creek. The reservoir, with a 35-acre surface area, inundates approximately 43 acres of the 6.03-square-mile drainage basin (Figure 1).

Vegetative composition within the watershed varies with slope, aspect, and soils. On better sites (north and east exposures and along streamcourses), Douglas fir (Pseudotsuga menziesii), madrone (Arbutus menziesii), and black oak (Quercus kelloggii) form the dominant overstory. On poorer sites (south and west exposures and areas with shallow soils), open ponderosa pine (Pinus ponderosa) stands with interspersed Oregon white oak (Quercus garryana) and manzanita (Arctostaphylos sp.) are the dominant vegetative species. Small patches of grassland habitat occur scattered within the watershed. Timber was harvested from the watershed in 1980.

The Morris Reservoir watershed is underlain by central belt Franciscan complex rocks, consisting of highly sheared and deformed graywacke and mudstone enclosing large blocks of heterogeneous rock types. The graywacke and mudstone

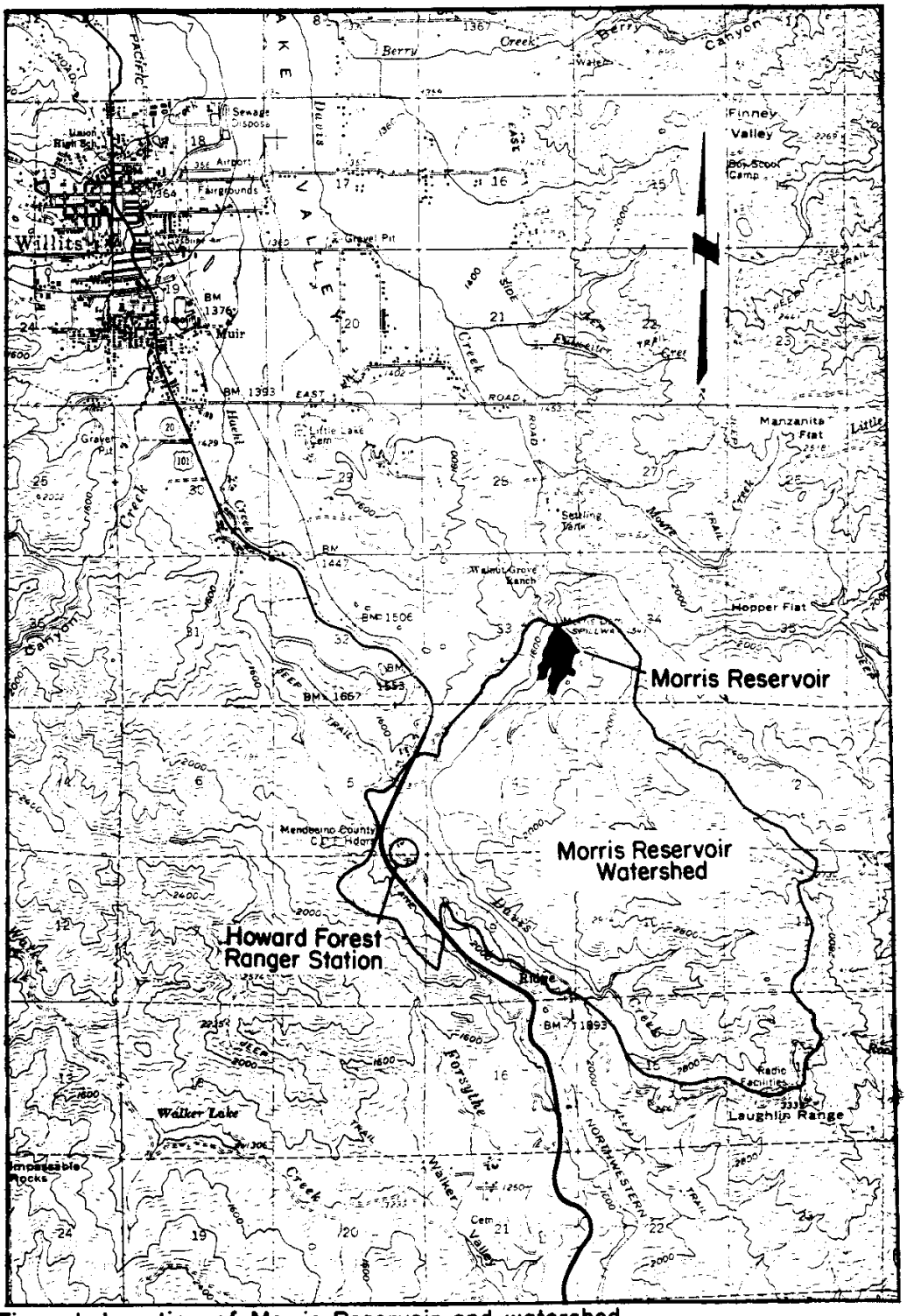

Figure I. Location of Morris Reservoir and watershed.

are easily eroded, exposing the heterogeneous mixture consisting of graywacke, chert, greenstone, serpentinite, blueschist, and limestone as resistant knobs projecting through hummocky, grass-covered hillslopes which are unstable and subject to landsliding. Erosion from exposed predominantly sodic-plagioclase ([Na, Ca] Al [Si, Al] Si_2O_8) soils following intense rainfall should produce runoff containing high levels of iron and manganese oxides, calcium, sodium, potassium, sulfate, chloride, chromium, and nickel (J. McMillan, DWR, pers. comm.).

Rainfall records (Table 1) of the Department of Water Resources obtained from the Department of Forestry's Howard Forest Ranger Station, located at an elevation of 1,900 feet within the Morris Reservoir watershed, indicate average annual rainfall of 49.7 inches for the period from July 1941 through June 1976. Twenty-three inches of the rainfall percolate into the soil, where it is used by vegetation or enters ground water aquifers, or evaporates (Kennedy/Jenks Engineers, 1985), allowing 26.7 inches of rainfall to contribute to surface runoff. The average annual volume of water produced from the 6.03-square-mile drainage is calculated to be 8,590 acre-feet.

LIMNOLOGY

Physical Characteristics

Sedimentation and Storage

The storage capacity of Morris Reservoir has been reduced due to the accumulation of sediments. Bathymetric soundings, using an Apelco Model 420 Recording Echo Sounder, were made during April of 1986 to determine the present storage capacity. Depth contours were established by taking a series of depth measurements at intervals across a series of transects. Contours were plotted on a map of the reservoir periphery obtained from an overhead aerial photograph (Figure 2). Reservoir storage was estimated using the formula $V = \sum_z^o [h/3(A_1 + A_2 + \sqrt{A_1 A_2})]$, where h is the vertical depth of each stratum, A_1 and A_2 are the areas of the upper and lower surfaces, respectively, of the stratum for which volume is being determined, and $\sum_z^o$ indicates the summation of surface (a) to bottom (z) strata (Wetzel, 1975).

Morris Reservoir is deepest near the dam. The depth from the top of the flashboards to the sediment surface at the dam is a maximum of 45 feet. Original depth from the top of the flashboards to the reservoir bottom was 53.7 feet. Sedimentation has reduced maximum reservoir depth by 8.7 feet.

Reservoir storage with flashboards in place was estimated from the current data at 623 acre-feet. Original storage with flashboards was 722 acre-feet. Storage has been reduced by 99 acre-feet due to sedimentation.

The volume of water that can presently be withdrawn through the upper outlet, which at the bottom of the outlet pipe is 19.6 feet below the crest of the flashboards, was calculated as 497 acre-feet. The bottom outlet pipe, the bottom of which is 44.3 feet below the crest of the flashboards, can deliver essentially all 623 acre-feet of stored water.

Table 1. Precipitation (in inches) record from the Department of Forestry, Howard Forest Ranger Station.

Season	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Total
1941-42	0	.03	.24	2.39	6.45	20.18	10.57	10.57	2.47	7.27	3.82	0	63.99
1942-43	0	0	.02	1.58	11.48	10.67	13.64	2.66	5.41	4.30	1.79	.26	51.81
1943-44	0	0	0	2.59	2.84	3.85	8.12	5.87	3.27	3.63	2.21	.65	33.03
1944-45	.10	.04	.25	3.00	12.00	8.50	2.93	5.98	7.79	1.15	3.62	0	45.36
1945-46	0	0	.22	5.36	9.80	18.55	5.32	5.14	3.51	.09	.45	.10	48.54
1946-47	.34	0	.49	1.35	7.27	4.05	2.71	3.75	8.39	1.44	.30	1.78	31.87
1947-48	0	0	.04	9.70	1.52	2.35	7.14	5.85	6.78	9.13	1.78	.12	44.41
1948-49	.02	.01	4.23	1.33	4.20	8.19	2.01	8.17	10.51	.25	.82	.04	39.78
1949-50	.28	0	0	.32	4.77	2.79	13.55	4.56	8.11	2.40	1.85	.97	39.60
1950-51	0	0	.08	9.20	6.24	9.75	14.30	8.51	3.55	2.43	1.65	0	55.71
1951-52	0	0	.16	4.01	10.04	17.72	13.46	8.34	5.41	1.31	1.22	1.54	63.21
1952-53	0	0	0	.40	4.53	19.11	18.21	.57	7.74	4.78	3.07	1.21	59.62
1953-54	0	.68	.02	2.27	8.40	4.00	14.87	5.18	5.48	5.45	0	1.28	47.63
1954-55	0	.98	.29	1.47	5.48	9.83	4.95	2.07	1.64	5.41	0	0	32.12
1955-56	0	0	.63	1.02	6.63	26.66	17.18	10.71	1.59	1.34	1.48	.14	67.38
1956-57	0	0	0	7.40	.24	1.77	7.78	8.95	8.63	2.25	6.07	0	43.09
1957-58	0	0	4.71	6.95	4.65	7.78	11.00	22.61	8.76	6.31	.72	1.87	75.36
1958-59	1.00	.03	.24	1.31	2.85	3.38	11.54	9.40	3.62	.96	.44	0	34.77
1959-60	0	.11	2.90	.38	.16	3.31	9.82	17.27	13.09	2.20	3.42	0	52.66
1960-61	0	0	0	1.23	10.00	8.39	5.40	7.83	10.28	2.73	2.32	.02	48.20
1961-62	0	0	.16	2.18	8.77	4.86	4.44	11.61	7.08	1.39	.66	0	41.15
1962-63	0	.59	1.31	11.78	4.53	7.24	7.20	3.25	7.31	10.45	.95	.08	54.69
1963-64	0	.03	.12	4.83	11.71	2.44	10.35	.44	4.13	.39	1.34	.33	36.11
1964-65	.10	0	0	1.81	15.59	26.01	9.69	1.98	2.60	6.57	0	.11	64.46
1965-66	.03	.57	.00	.64	11.05	5.73	12.65	6.07	4.25	3.01	.04	.00	44.04
1966-67	.00	.20	.30	.00	11.98	8.58	14.96	.82	10.21	5.73	.85	1.78	55.41
1967-68	.00	.03	.12	3.48	5.33	6.99	12.28	7.20	5.41	.36	1.67	.00	42.87
1968-69	.00	1.33	.21	2.91	5.38	17.66	19.17	11.29	1.92	2.94	.11	.20	63.12
1969-70	.00	.00	.16	2.69	1.87	14.91	26.55	4.81	2.49	1.36	.39	.62	55.85
1970-71	.00	.00	.00	3.88	13.60	14.83	9.94	1.00	11.14	2.65	.93	.06	58.03
1971-72	.00	.47	1.14	.84	5.87	8.22	6.75	6.54	3.59	3.51	.99	.56	38.48
1972-73	.00	.51	1.90	3.41	8.03	9.44	13.81	7.60	6.08	.38	.32	.00	51.48
1973-74	.00	.02	2.05	5.47	20.11	9.30	12.87	7.33	15.43	2.27	.15	.05	75.05
1974-75	1.25	.03	.00	2.39	2.43	6.11	6.47	12.41	15.94	2.57	.20	.00	49.80
1975-76	.03	.28	.00	5.33	3.59	3.28	.74	9.55	4.30	3.47	.00	.02	30.59

Figure 2. Bathymetric map of Morris Reservoir during April 1986.

Water Quality

Physical water quality characteristics were generally measured biweekly at three locations on Morris Reservoir, the three principal tributaries to the reservoir, the outfall of the hypolimnetic pump, and from an untreated water tap at the Water Treatment Plant (Figure 3). At the reservoir monitoring locations, water temperature, and dissolved oxygen concentration were measured with a Yellow Springs Instrument Model 58 Meter at 1-meter (3.28-ft) intervals from the surface to the bottom. Water samples were obtained with a Van Dorn style sampler at 3-meter (9.8-foot) intervals from surface to bottom for measurement of alkalinity, apparent color, electrical conductivity, odor, pH, and turbidity. Alkalinity was determined by potentiometric titration (APHA 1985). Odor was determined by olfactory perception at the time of sampling. Equipment used for the other analyses included a Taylor Color Analyzer, Hach Model 16300 Portable Conductivity Meter, Hellige pH Comparator, Corning Digital 110 pH meter, and a Hach Model 2100 A Turbidimeter. Water clarity was also measured using a Seechi disk.

Water samples from three tributaries and the treatment plant were also analyzed for water temperature, dissolved oxygen, alkalinity, electrical conductivity, pH, and turbidity using the same methods and equipment as at the reservoir locations, except that temperature was determined with a calibrated thermometer and dissolved oxygen was determined by the azide modification of the iodometric method (APHA 1985). Streamflow was measured with a Price or Pygmy current meter (USBR 1967).

Water from the hypolimnetic pump was analyzed for temperature, alkalinity, color, electrical conductivity, pH, and turbidity using the same methods as at the lake and stream monitoring locations.

Temperature. Water temperature affects the beneficial uses of water, including habitat for fish and other aquatic organisms, irrigation for crops, recreation, and domestic water supply. Temperature also affects lake dynamics through effects on water density. The infusion of heat during spring and summer causes deep water bodies to stratify into three distinct layers based on density differences. The upper layer, termed the epilimnion, contains the warmest water. The coldest water is found in the bottom layer, which is termed the hypolimnion. The transitional layer between the warmer epilimnion and colder hypolimnion is called the metalimnion. The metalimnion is also the location of the thermocline, which is defined as the region where water temperature changes at least 1°C (1.8°F) with each meter (3.28 ft) of depth. Thermal stratification effectively separates a lake or reservoir into distinct regions which experience separate physical, chemical, and biological processes. Cooler air temperatures during the fall cause epilimnetic temperatures to cool. Complete mixing by wind action occurs when temperature induced density differences no longer exist between the surface and bottom.

Water temperature differences between the surface and bottom of Morris Reservoir near the dam were already apparent by April of 1986 (Appendices 1 and 2). The thermocline was located between depths of 3 and 7 meters (9.8 and 23.0 ft) in April. As seasonal warming during spring and summer occurred, the thermocline was driven progressively deeper and compressed until August 21, at which time the thermocline was located between 6 and 8 meters (19.7 and

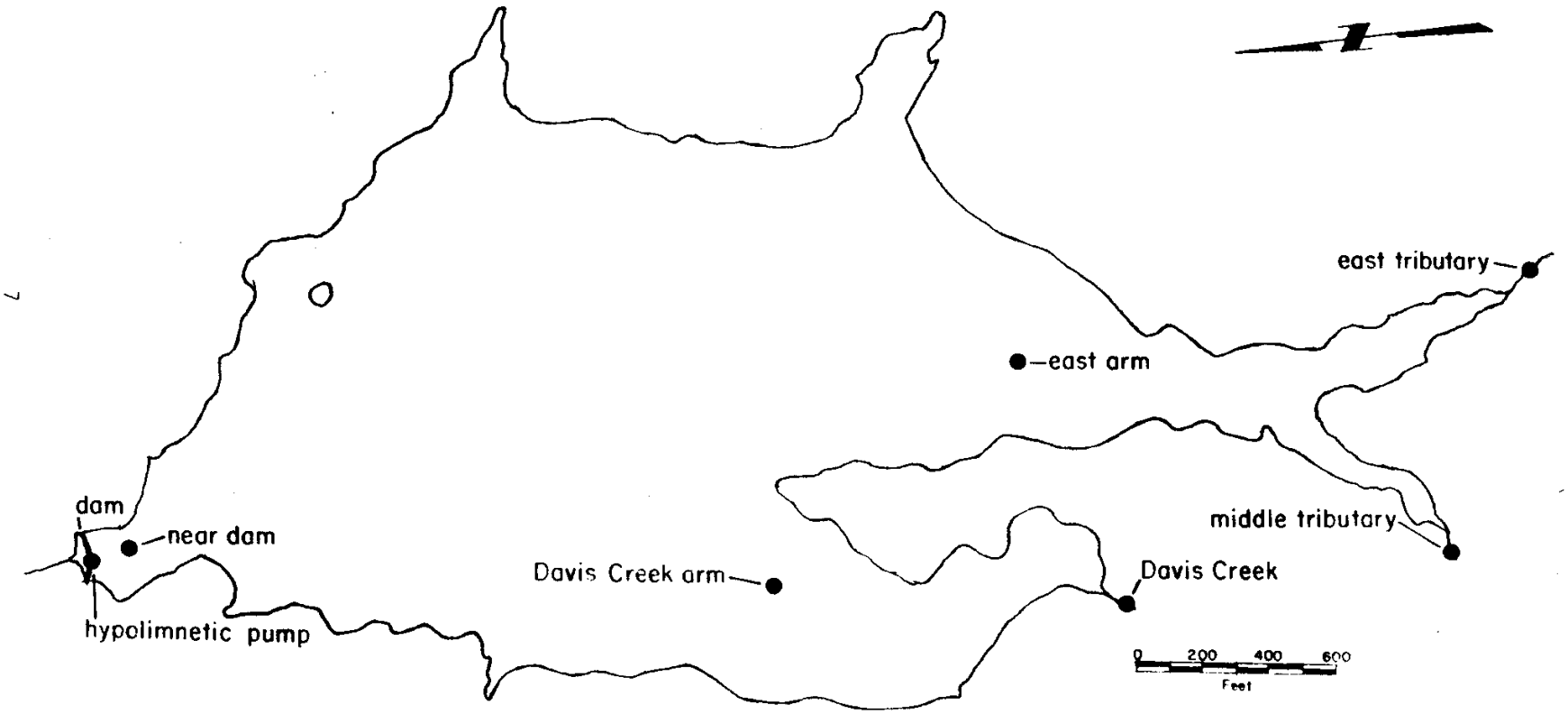

Figure 3. Water quality monitoring locations at Morris Reservoir.

26.3 ft) in depth. By late September, epilimnetic temperatures had cooled creating nearly isothermal temperatures from surface to bottom. Water column temperatures were essentially uniform through the winter, except for occasional surface warming on warmer days. Thermal stratification began again by early April of 1987. Surface water temperatures ranged from a high of 25.8°C (78°F) on August 14, 1986, to a low of 6.1°C (43°F) on January 22, 1987. Water temperatures at the bottom were 14.3°C (58°F) and 5.8°C (42°F) during August and January, respectively.

Water temperature differences between the surface and bottom of Morris Reservoir in the Davis Creek arm and the unnamed east tributary arm were also apparent by April of 1986. Temperatures became essentially uniform in the shallower Davis Creek arm because of heating by late June, and in the east tributary by early August. Temperatures remained uniform from surface to bottom as the reservoir cooled during the fall and through the winter. Stratification was again apparent in both arms by early April of 1987. Temperatures were warmest in August, ranging from 26.2°C (79°F) at the surface to 25.2°C (77°F) at the bottom in the Davis Creek arm and 26.0°C (78.8°F) at the surface to 24.2°C (75.6°F) at the bottom in the east tributary arm. Coolest temperatures occurred in January, ranging from 5.8°C (42°F) at the surface to 5°C (41°F) at the bottom in the Davis Creek arm and 5.8°C (42.4°F) at the surface to 5.6°C (42.1°F) at the bottom in the east tributary arm.

Water temperatures in the tributaries ranged to 20.6°C (69°F) during late July and 3.9°C (39°F) in January. Only Davis Creek contained flow during the summer, but temperatures were similar in all three tributaries during the winter.

Water temperatures at the Water Treatment Plant ranged from 27.2°C (81°F) in July to 6.4°C (43.5°F) in January. Water temperatures were controlled more by ambient air temperatures along the distribution pipe than by the temperatures in Morris Reservoir.

Water temperatures from the hypolimnetic pump ranged up to 21.1°C (70°F) before pumping was discontinued in late August. Water temperatures from the pump reflected reservoir temperatures approximately 7 meters (23 ft) below the surface.

Dissolved Oxygen. Dissolved oxygen content of water is important for the maintenance of aquatic life and, perhaps more important in water supply reservoirs, determining the end products of biochemical reactions and solubility of various chemical elements. Dissolved oxygen concentrations are largely affected by temperature, photosynthesis by plants, respiration by plants and animals, and decomposition of organic materials. Solubility of oxygen in water is greatest at coldest temperatures, and decreases as waters warm. While photosynthesis by plants increases the oxygen content of water, respiration by plants and animals and decomposition of organic materials reduces the oxygen content. Oxygen content of water determines whether chemical species will be oxidized or reduced. Oxidation of many chemical species results in the formation of insoluble precipitates, while reduction of compounds in the absence of oxygen generally increases solubility.

Oxygen concentrations from Morris Reservoir near the dam were at high levels during spring and summer at the surface, but became depleted as early as May in 1986 at the bottom (Appendices 1 and 3). Thermal stratification during spring and summer prevented mixing of the oxygenated epilimnion with the anoxic hypolimnion. Supersaturation occurred at times during spring and early summer at depths of around 3 to 5 meters (9.8 to 16.4 ft) as a result of high rates of photosynthesis by algae avoiding the more intense light nearer the surface. Anoxic conditions in the hypolimnion persisted until stratification broke down in mid-September. Mixing of anoxic water resulted in reduced oxygen concentrations throughout the water column by late September. Weak stratification occurred during warm, calm weather in early October, resulting in an increased oxygen concentration in the epilimnion due to atmospheric exchange and photosynthesis, and oxygen depletion in the hypolimnion due to decomposition of excessive amounts of organic materials. Cooling temperatures, increased wind induced atmospheric mixing, and decreased organic production allowed dissolved oxygen levels to increase through the winter with uniform distribution from surface to bottom. Thermal stratification beginning in the early spring of 1987 resulted in oxygen stratification with near depletion at the bottom by May.

Oxygen levels in the Davis Creek arm of Morris Reservoir were high at both surface and bottom throughout the year. Wind induced mixing of the shallow water column, photosynthesis by beds of aquatic macrophytes, and inflow of Davis Creek maintained oxygenation.

Thermal stratification in the deeper east arm of Morris Reservoir contributed to the development of anoxic conditions by mid-May. Declining water levels and a deepening epilimnion during the summer eventually resulted in isothermal conditions from surface to bottom in shallower water, allowing mixing from surface to bottom and uniform oxygen levels through the winter.

Dissolved oxygen levels in the tributaries to Morris Reservoir were generally at high levels. Oxygen levels were occasionally depressed when streamflow had ceased, allowing stagnant conditions to develop.

Oxygen concentrations in water from the treatment plant were at low levels during spring and summer, but at high levels during winter. The dissolved oxygen levels at the treatment plant reflect those present in Morris Reservoir at the water withdrawal elevation.

Alkalinity. Alkalinity, which is a measure of the buffering capacity of water, was determined as both a field and laboratory measurement. Alkalinity is discussed in the later section on chemical characteristics.

Color. Color occurs in water from the presence of high concentrations of metallic ions (primarily iron and manganese) and complex organic compounds resulting from the decomposition of naturally occurring organic materials such as phytoplankton (USEPA 1986). The true color of water is determined on samples for which turbidity has been removed. Turbidity may be removed by filtration or centrifugation. However, filtration may also remove some true color and centrifugation results vary with the nature of the sample and size and speed of the centrifuge. The apparent color of water includes effects of both dissolved and suspended materials. The effects of color on water supplies are primarily aesthetic. True color in finished waters should not exceed 15 color units.

Using standard coagulation, sedimentation, and filtration processes, water sources may contain up to 75 color units and still produce finished water within the acceptable limit.

Apparent color was determined from water samples beginning on August 21, 1986. Apparent color ranged from 15 to 20 units during the summer to 80 units during the winter at the surface of Morris Reservoir near the dam, and from 20 to 60 units during the summer to 90 units during the winter from the bottom (Appendix 1).

Apparent colors in the Davis Creek and east tributary arms of the reservoir were more uniform from surface to bottom. Values in the Davis Creek arm ranged from 10 to 20 units during the summer to 100 units during the winter. In the east tributary arm, color ranged from 10 to 20 units during the summer to 120 units during the winter.

The tributaries produced apparent color ranging from 5 to 20 units in Davis Creek, 10 to 60 units in the middle tributary, and 5 to 40 units in the east tributary. Color units were lowest during the summer and highest during the winter.

Color at the treatment plant and hypolimnetic pump reflected the values from the depth of water withdrawal in Morris Reservoir near the dam. Apparent color at the treatment plant ranged from 25 to 40 units during the summer to 90 units during the winter. Apparent color measured during August from the hypolimnetic pump was 40 units.

Apparent color in Morris Reservoir and at the Water Treatment Plant on occasion exceeded the maximum recommended for aesthetic appeal. However, since apparent color includes the effects of turbidity, water treatment processes that reduce water turbidity would probably reduce true color to an aesthetically acceptable level.

Electrical Conductivity. Electrical conductivity is a measure of the ability of water to carry an electrical current and is dependent upon the concentration of mineral ions in solution. The maximum contaminant level for electrical conductivity in drinking water is 1,600 micromhos per centimeter (μmhos/cm) (DHS 1977).

Electrical conductivity values from Morris Reservoir near the dam were lowest during the spring and increased during the summer and fall. Surface electrical conductivity was higher than that at the bottom during the spring and early summer, reflecting higher concentrations of dissolved minerals at the surface. Electrical conductivity was at essentially uniform levels from surface to bottom during the winter, except at the very surface where rainfall caused temporarily lowered values due to dilution. Values at the surface ranged from 90 μmhos/cm in the spring to 306 μmhos/cm in December, and ranged at the bottom from 121 μmhos/cm in the spring to 317 μmhos/cm in December (Appendix 1).

Slight differences are apparent between surface and bottom electrical conductivity measurements during the spring in the Davis Creek and east tributary arms, but essentially uniform conditions exist the rest of the year

except during storms when surface values are reduced by dilution. Electrical conductivity values ranged from 89 µmhos/cm in March to 301 µmhos/cm in November in the Davis Creek arm, and 91 µmhos/cm in March to 315 µmhos/cm in December in the east tributary arm.

Electrical conductivities in the tributaries to Morris Reservoir increased as streamflow decreased through the summer. Conductivity in Davis Creek ranged up to 334 µmhos/cm by November, but decreased to 161 µmhos/cm with increased streamflow in March. Prior to becoming dry, electrical conductivity ranged up to 117 µmhos/cm in the middle tributary in April and 156 µmhos/cm in the east tributary in June. High streamflow decreased electrical conductivity levels to 87 µmhos/cm in the middle tributary in March and 85 µmhos/cm in the east tributary in February.

Conductivity levels at the treatment plant and hypolimnetic pump reflect values found at the withdrawal depth from Morris Reservoir near the dam. Values ranged from 110 µmhos/cm in March to 312 µmhos/cm in December at the treatment plant, and 238 to 251 µmhos/cm during August at the hypolimnetic pump.

Maximum electrical conductivity levels present in Morris Reservoir and at the Water Treatment Plant are well below the maximum contaminant level and recommended maximum for drinking water.

Odor. Many substances can result in disagreeable tastes and odors in water. Phytoplankton, macrophytes, bacteria, decaying organic materials, and certain inorganic compounds and chemical elements can cause problems associated with tastes and odors. Non-volatile inorganic compounds and chemical elements produce tastes without producing odors, but odor-producing materials also result in the sensation of disagreeable tastes. Substances causing tastes but not odors include dissolved inorganic salts of copper, iron, manganese, potassium, sodium, and zinc at concentrations as low as a few tenths of a milligram per liter (APHA 1985). Tastes were not analyzed due to the inherent danger of ingesting untreated surface waters required by tasting.

Odor was first detected in early July in Morris Reservoir near the dam. Water samples collected from the surface, 3-meter (9.8-ft), and 6-meter (19.7-ft) depths produced no discernible odors, but water collected from the 9-meter (29.5-ft) depth produced a slight odor, while water collected from the 12-meter (39.4-ft) depth produced a strong odor (Appendix 1). Odor was confined to the hypolimnion, which was anoxic. Odor from the hypolimnion persisted until early September when cooling temperatures caused thermal destratification, which allowed mixing and aeration. No odors were discernable following the fall turnover.

Odor was not detected from the other monitoring locations on Morris Reservoir nor the three tributaries. The deeper east tributary arm of Morris Reservoir was anoxic at the very bottom for a brief period during early summer, but, otherwise, all monitoring locations maintained aerobic conditions.

Monitoring for odor was not conducted at the treatment plant. However, odor was detected from the hypolimnetic pump which, based on observations of the other parameters, draws water from the same level as the upper

intake for the Water Treatment Plant. Odor was detected from water from the hypolimnetic pump during July and August.

The odors detected were sensed to be caused by hydrogen sulfide. However, olfactory perception is not sufficient to discern the likely presence of other odiferous substances in the presence of the overpowering sulfide.

pH. The term pH designates the relative acidity or basicity of water. The pH values less than 7 are acidic, over 7 are basic, and at 7 are neutral. The pH of water affects the solubility and speciation of many other substances, including metallic compounds. The pH in most bicarbonate-type water is governed by the carbon dioxide-bicarbonate-carbonate (CO_2-HCO_3-CO_3) buffering system. The pH of raw water for domestic use affects taste, corrosivity, efficiency of chlorination, and treatment processes such as coagulation (McKee and Wolf 1963). The recommended range for protection of domestic water supplies is from 5 to 9 pH units.

The pH values from Morris Reservoir near the dam were higher at the surface than the bottom during reservoir stratification, but were nearly identical from surface to bottom at other times. Field pH measurements were usually lower than laboratory determinations. Field pH values ranged from 7.9 at the surface to 6.6 at the bottom, while laboratory measurements ranged from 8.1 at the surface to 6.9 at the bottom.

Higher pH values were also found from the surface than the bottom in the Davis Creek and east tributary arms of Morris Reservoir. Field pH values in the Davis Creek arm ranged from 8.0 on the surface to 7.1 on the bottom, and in the east tributary arm from 8.1 on the surface to 7.0 on the bottom. Laboratory measurements ranged from 8.2 and 8.3 on the surface in the Davis Creek and east tributary arms, respectively, to 7.0 at the bottoms.

The pH values in Davis Creek ranged from 8.2 to 6.9 for field measurements and 8.3 to 7.2 for laboratory measurements. Middle tributary pH levels ranged from 7.2 to 6.6 in the field and 7.9 to 6.7 in the laboratory. The east tributary pH values ranged from 7.8 to 6.9 for field measurements and 8.3 to 6.9 for laboratory measurements.

Waters from the treatment plant and hypolimnetic pump had pH levels corresponding to those found at the withdrawal level in Morris Reservoir near the dam. The pH value ranged from 7.4 to 6.8 in field determinations and 8.0 to 7.1 in laboratory determinations at the treatment plant, and 7.1 to 7.0 in the field and 7.2 to 7.3 in the laboratory for measurements from the hypolimnetic pump during August.

The pH values of water in Morris Reservoir are within the range for protection of beneficial uses. The pH levels were higher at the surface than the bottom due to various biologically mediated reactions. Algal photosynthesis near the surface removes carbon dioxide (CO_2) causing pH levels to increase. Respiration and decomposition in the hypolimnion increases the carbon dioxide content of the water, thereby shifting the carbonate equilibrium reaction to increase hydrogen ions and lower the pH. Field and laboratory pH values probably differed due to interference with the colorimetric field method or potentiometric laboratory method by substances in the water or changes in the carbonate equilibrium during transport of laboratory samples.

Turbidity. Turbidity is an indication of the clarity of water. Substances causing turbidity in water include suspended clays, silt, microorganisms, organic detritus, and soluble colored organic compounds. A maximum contaminant level of 5 turbidity units has been established for drinking water (DHS 1977).

Turbidity levels from Morris Reservoir near the dam were generally lower near the surface than near the bottom during the period of thermal stratification, but more uniform throughout the water column during the rest of the year. Turbidity levels were somewhat variable at the surface and bottom during stratification, which was due to phytoplankton production and subsequent settling. Turbidity levels were high from both the surface and bottom during winter from sediments carried in storm runoff and resuspension of flocculent sediments from the reservoir bottom. Turbidity levels at the bottom remained elevated longer than at the surface during the spring due to settling of sediments. Turbidity levels during stratification ranged from 0.4 to 1.7 nephelometric units (NTU) at the surface and 2.3 to 7.7 NTU at the bottom (Appendix 1). During winter, turbidity levels ranged up to 21 NTU at the surface and 17 NTU at the bottom.

Turbidity levels in the Davis Creek and east tributary arms of Morris Reservoir were also lower at the surface than the bottom during the summer and somewhat variable. Turbidity levels increased substantially with the influx and resuspension of sediments during winter storms. Turbidity levels during the summer ranged up to 1.6 NTU at the surface and 7.6 NTU at the bottom. Winter turbidity levels ranged up to 21 NTU at the surface and 32 NTU at the bottom.

Summer increases of turbidity in streams tributary to Morris Reservoir are due to physical disturbance rather than the production of phytoplankton. Bank sloughing or channel disturbance from animals are likely causes of the occasionally higher turbidity levels during the summer. Surface erosion, bank sloughing, and resuspension of stream bottom deposits are sources of materials contributing to higher turbidity level in the streams during the winter. Turbidity levels in the tributary streams ranged from 0.2 to 6.7 NTU during the summer and up to 7.3 NTU during the winter.

Turbidity levels from the treatment plant and hypolimnetic pump did not consistently reflect levels in Morris Reservoir at the withdrawal elevation. Aggregation, dissolution, and decomposition in the transport pipes of inorganic and organic materials contributing to turbidity in Morris Reservoir could be responsible for the observed values. Turbidity ranged at the treatment plant from 1.1 to 20 NTU, and at the hypolimnetic pump during August from 2.7 to 3.4 NTU.

Secchi Depth. Transparency or visibility into water is commonly determined with a 20-centimeter (8-in) black and white Secchi disk, named after its Italian inventor. The Secchi depth is the average depth at which the disk just disappears as it is lowered into the water and just reappears as it is raised. Secchi depth corresponds to the depth to which approximately 5 percent incident solar radiation penetrates (Hutchinson 1957), which closely parallels the 1 percent solar radiation penetration required for photosynthesis by algae. Transparency of water is affected by both dissolved and particulate matter.

Secchi depth was greatest at all three monitoring locations on Morris Reservoir during the spring (Appendix 1 and Figure 4). Transparency fluctuated through the summer due to surges in phytoplankton growth. Lowest Secchi depths were found during the winter due to high levels of suspended materials. Secchi depths ranged from approximately 7.9 meters (25.5 ft) during the spring to about 0.4 meter (1.3 ft) during the winter.

Chemical Characteristics

Water Quality

Water samples for chemical analyses at the Department of Water Resources' Bryte Chemical Laboratory were collected monthly from April of 1986 through June of 1987. Samples were collected from the surface and near the bottom of Morris Reservoir near the dam, the three principal tributaries, and the untreated water tap at the Water Treatment Plant (Figure 3). Additional water samples were collected from the hypolimnetic pump outfall to the reservoir surface during July and August of 1986.

Chemical parameters analyzed each month from the reservoir, tributary, and treatment plant monitoring locations included nutrients (dissolved nitrate plus nitrite, ammonia, and orthophosphate, and total organic nitrogen and phosphorus), dissolved minerals (calcium, magnesium, hardness, and sulfate), and total heavy metals (copper, iron, and manganese). Analyses were conducted during the months of April and September for additional dissolved minerals (sodium, potassium, alkalinity, chloride, and boron) and total metals (arsenic, cadmium, chromium, aluminum, lead, mercury, selenium, and zinc). Chemical parameters analyzed from the hypolimnetic pump included nutrients (dissolved nitrate plus nitrite, ammonia, and orthophosphate, and total organic nitrogen and phosphorus) for both July and August, and dissolved minerals (calcium, magnesium, hardness, and sulfate) and total heavy metals (copper, iron, and manganese) only for August.

Samples were collected in clean polyethylene bottles for transport to the laboratory. Surface water samples were collected by immersing the container into the water until full. The samples from the bottom of Morris Reservoir were collected with a Van Dorn style sampler, while the pump was sampled by holding the bottle under the water stream.

All samples were preserved according to U. S. Environmental Protection Agency standards (USEPA, 1979). Laboratory analyses conformed to accepted procedures (APHA, 1985).

Nitrogen. The forms of nitrogen of greatest interest in surface waters are nitrate (NO_3), nitrite (NO_2), ammonia (NH_3), organic nitrogen, and nitrogen gas (N_2), and are biochemically interconvertible in the nitrogen cycle (Figure 5). Organic nitrogen is naturally bound in biological products, such as algae, and typically varies in concentration from a few tenths of a milligram per liter (mg/L) in some lakes to more than 20 mg/L in raw sewage (APHA, 1985). Organic nitrogen concentrations in highly productive (eutrophic) Clear Lake in Lake County, California, have varied from 0.3 mg/L to 1.8 mg/L (Gaonker, 1971). Nitrate usually occurs in trace quantities in surface waters

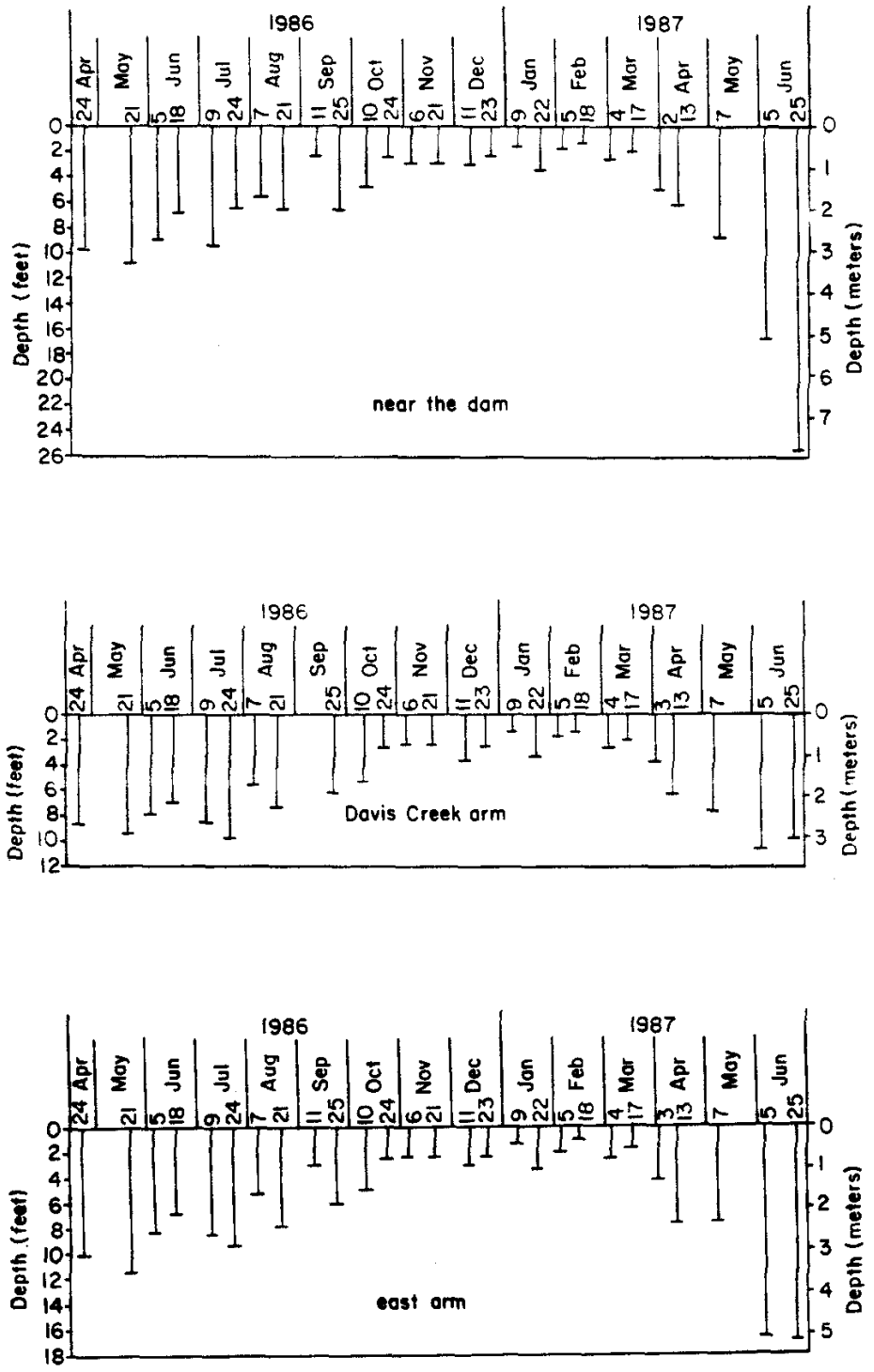

Figure 4. Secchi depths from the three stations on Morris Reservoir from April 24, 1986 to June 25, 1987.

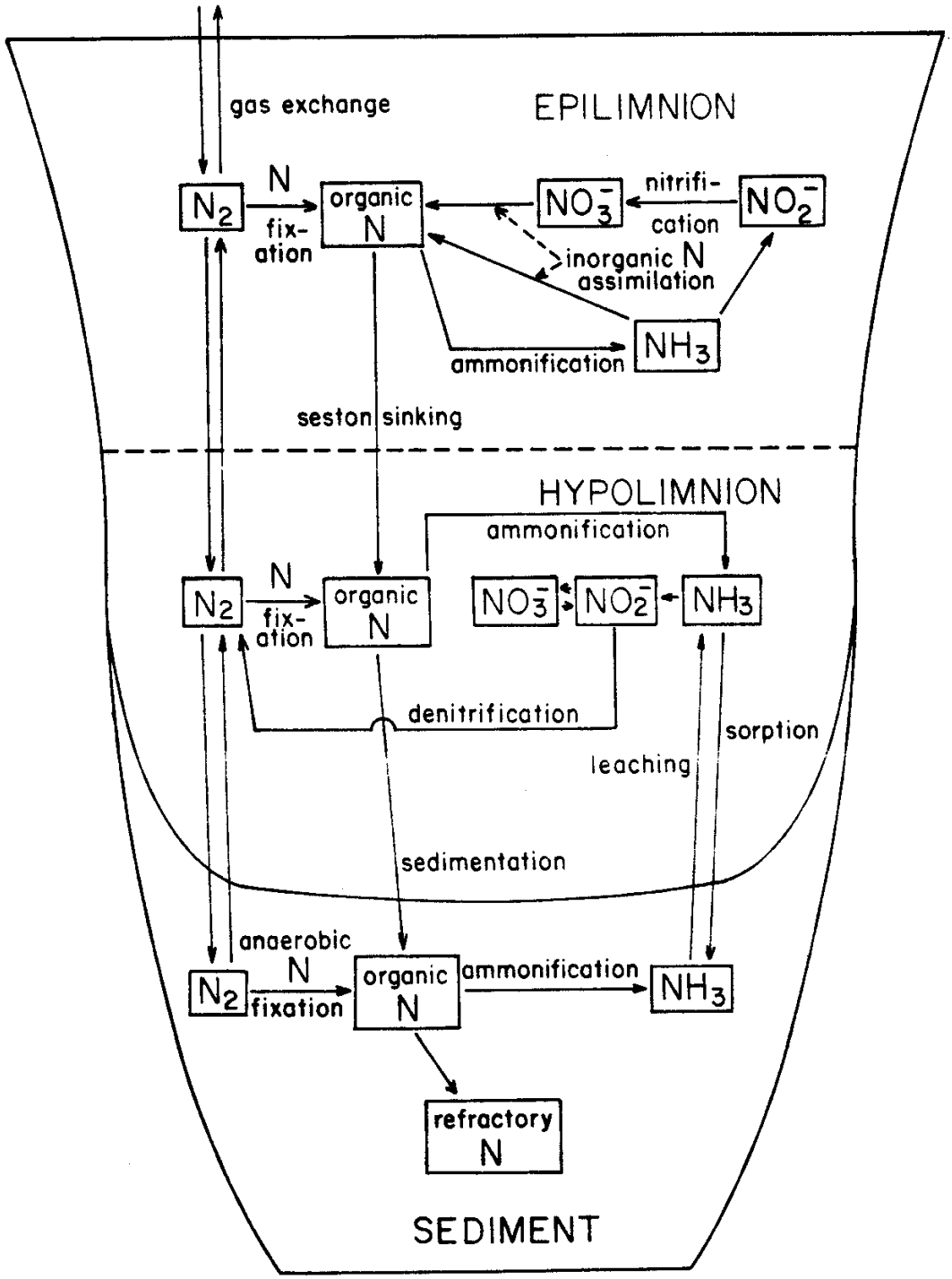

Figure 5. General nitrogen cycle for freshwater lakes. (Modified from Brezonik 1973.)

and is an essential and sometimes limiting nutrient for algal growth. Concentrations of nitrate reported for Clear Lake range from 0.01 to 0.53 mg/L. Nitrite is an intermediate oxidation state of nitrogen formed during the reduction of nitrate to ammonia or oxidation of ammonia to nitrate. Since the oxidation/reduction reaction proceeds so quickly, usually very little nitrite is ever present (McKee and Wolf, 1963). Nitrate and nitrite are reported together as total oxidized nitrogen. Ammonia naturally occurs in surface water through deamination of organic nitrogen. Ammonia has been found to be toxic to fish at concentrations as low as 0.3 mg/L and inhibits the growth of algae at concentrations of 0.4 mg/L. Concentrations of ammonia have been found at less than a hundredth of a mg/L in some unproductive lakes and up to 0.61 mg/L in Clear Lake. Nitrogen gas occurs in natural waters in equilibrium with atmospheric nitrogen. Nitrogen gas can be produced in water through denitrification of nitrite, but is not available for biological uptake except through anaerobic N-fixation by certain bacteria and atmospheric N-fixation by certain algae of the Cyanophyta (blue-green) group.

Total oxidized nitrogen (NO_3 + NO_2) concentrations were at low levels (0.00 to 0.04 mg/L) at Morris Reservoir from both surface and bottom sampling locations, as well as at the three inflowing tributaries and the hypolimnetic pump, throughout the study (Table 2). Concentrations ranged up to 0.24 mg/L of total oxidized nitrogen at the treatment plant, with highest concentrations occurring during the late summer-early fall period.

Ammonia concentrations from the epilimnion of Morris Reservoir were low (0.00 to 0.05 mg/L) throughout the study. Concentrations of ammonia in the hypolimnion of Morris Reservoir, however, were at high levels (up to 0.47 mg/L) during summer stratification. Ammonia levels in the tributaries were usually at low levels (up to 0.03 mg/L), except in Davis Creek during November and December (0.12 and 0.10 mg/L, respectively). During these months, the water storage in Morris Reservoir was extremely low and Davis Creek was sampled downstream of an organically rich delta normally flooded at higher reservoir storage levels. Highest ammonia levels (0.16 mg/L) at the treatment plant and hypolimnetic pump occurred during August.

Organic nitrogen ranged from 0.2 to 0.8 mg/L from the surface of Morris Reservoir and 0.2 to 1.4 mg/L from the bottom. Tributary organic nitrogen levels ranged up to 0.2 mg/L. Waters from the treatment plant and hypolimnetic pump contained up to 0.7 mg/L of organic nitrogen.

Thermal stratification has a pronounced effect on the nitrogen cycle in Morris Reservoir. Dissolved nitrogen is rapidly recycled in the epilimnion. Ammonia produced by the decomposition of organic materials (primarily algae and their by-products) is rapidly oxidized into nitrite and nitrate, or is directly assimilated into the production of organic and inorganic materials. Nitrite and nitrate are also rapidly assimilated into organic materials. Much of the organic production in the epilimnion settles to deeper reservoir strata before decomposition occurs. These processes maintain rather low levels of nitrogen in the epilimnion. Aerobic decomposition of organic materials in the thermocline results in release of ammonia, with subsequent conversion into nitrite and nitrate. Since the thermocline is located below the euphotic zone where sufficient light penetrates to allow the production of organic materials through photosynethsis, nitrate, nitrite, and ammonia accumulate to higher

Table 2a. Laboratory analyses results (in mg/L) for water collected from the surface of Norris Reservoir near the dam.

	4/24/86	5/21/86	6/18/86	7/09/86	8/07/86	9/11/86	10/10/86	11/06/86	12/11/86	1/09/87	2/05/87	3/04/87	4/03/87	5/07/87	6/05/87	Range
Nitrogen																
Nitrate plus Nitrite (T)	0.00	0.00	0.00	0.01	0.01	0.00	0.02	0.01	0.00	0.04	0.00	<0.01	<0.01	<0.01	0.04	0.00-0.04
Ammonia (T)	0.00	0.00	0.00	0.01	0.01	0.00	0.03	0.01	0.00	0.02	0.05	0.01	<0.01	<0.01	0.03	0.00-0.05
Organic Nitrogen (T)	0.2	0.3	0.4	0.4	0.3	0.5	0.3	0.4	0.4	0.5	0.4	0.3	0.2	0.8	0.3	0.2-0.8
Phosphorus																
Phosphorus (T)	0.02	0.01	0.01	0.04	0.02	0.04	0.02	0.03	0.02	0.05	0.04	0.03	0.02	0.01	<0.01	<0.01-0.05
Orthophosphate (D)	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00	<0.01	<0.01	<0.01	<0.01	0.00-0.01
Sulfur																
Sulfate (D)	6	8	8	8	10	8	9	10	12	9	6	5	2	6	6	2-12
Salinity																
Calcium (D)	24	26	29	31	34	38	38	40	42	22	12	14	13	17	20	12-42
Magnesium (D)	7	8	8	9	9	10	10	11	12	6	5	5	5	7	6	5-12
Hardness (D)	89	98	106	115	122	136	136	145	155	80	50	56	53	67	74	50-155
Sodium (D)	5	-	-	-	-	7	-	-	8	-	-	-	4	4	5	4-8
Potassium (D)	1.0	-	-	-	-	1.5	-	-	1.3	-	-	-	0.6	0.9	0.8	0.6-1.5
Chloride (D)	2	-	-	-	-	3	-	-	-	-	-	-	2	-	-	2-3
Alkalinity	85	-	-	-	-	134	-	-	-	-	-	-	51	-	-	51-134
Metallic Micronutrients																
Boron (T)2	0.0	-	-	-	-	0.1	-	-	-	-	-	-	0.0	-	-	0.0-0.1
Copper (T)	-	0.077	0.025	0.150	0.140	0.052	0.166	0.015	0.008	0.009	0.006	0.010	0.005	0.045	0.025	0.005-0.166
Iron (T)	-	0.080	0.063	0.098	0.157	0.338	0.170	0.340	0.300	1.45	1.54	1.10	0.700	0.455	0.043	0.043-1.54
Manganese (T)	-	0.021	0.012	0.037	0.093	0.186	0.081	0.236	0.130	0.116	0.026	0.027	0.014	0.010	0.008	0.008-0.236
Zinc (T)	-	-	-	-	-	0.004	-	-	-	-	-	-	0.007	-	-	0.004-0.007
Other Metals																
Aluminum (T)	0.034	-	-	-	-	0.168	-	-	-	-	-	-	0.280	-	-	0.034-0.280
Arsenic (T)	-	-	-	-	-	0.0017	-	-	-	-	-	-	0.0000	-	-	0.0000-0.0017
Cadmium (T)	-	-	-	-	-	0.000	-	-	-	-	-	-	0.000	-	-	0.000
Chromium (T)	-	-	-	-	-	0.002	-	-	-	-	-	-	0.004	-	-	0.002-0.004
Lead (T)	-	-	-	-	-	0.00	-	-	-	-	-	-	0.00	-	-	0.00
Mercury (T)	-	-	-	-	-	0.0001	-	-	-	-	-	-	0.0001	-	-	0.0001
Selenium (T)	-	-	-	-	-	0.0000	-	-	-	-	-	-	0.0000	-	-	0.0000

Note: T = total, D = dissolved

Table 2b. Laboratory analyses results (in mg/L) for water collected from the bottom of Norris Reservoir near the dam.

	4/24/86	5/21/86	6/18/86	7/09/86	8/07/86	9/11/86	10/10/86	11/06/86	12/11/86	1/09/87	2/05/87	3/04/87	4/03/87	5/07/87	6/05/87	Range
Nitrogen																
Nitrate plus Nitrite (T)	0.02	0.01	0.00	0.01	0.01	0.00	0.03	0.01	0.00	0.04	0.03	0.03	0.02	0.03	<0.01	0.00-0.04
Ammonia (T)	0.01	0.01	0.11	0.28	0.47	0.29	0.45	0.01	0.01	0.03	0.07	0.07	0.05	0.03	0.10	0.01-0.47
Organic Nitrogen (T)	0.2	0.3	0.4	0.9	1.1	1.4	0.9	0.4	0.6	0.4	0.3	0.4	0.2	0.2	0.7	0.2-1.4
Phosphorus																
Phosphorus (T)	0.04	0.03	0.10	0.16	0.18	0.16	0.11	0.04	0.09	0.05	0.03	0.04	0.06	0.04	0.07	0.03-0.18
Orthophosphate (D)	0.00	0.00	0.02	0.02	0.02	0.01	0.03	0.00	0.00	0.00	0.00	<0.01	<0.01	<0.01	0.01	0.00-0.03
Sulfur																
Sulfate (D)	4	5	4	5	4	8	8	10	12	10	9	7	2	4	4	2-12
Salinity																
Calcium (D)	13	18	18	22	30	37	38	48	41	23	18	18	18	15	15	13-48
Magnesium (D)	5	6	6	7	8	10	10	11	12	7	7	6	6	6	5	5-11
Hardness (D)	53	70	70	84	108	134	136	165	152	86	74	70	70	62	58	53-165
Sodium (D)	4	-	-	-	-	7	-	-	8	-	-	-	4	4	4	4-8
Potassium (D)	0.9	-	-	-	-	1.4	-	-	1.3	-	-	-	0.7	0.8	0.7	0.7-1.4
Chloride (D)	2	-	-	-	-	3	-	-	-	-	-	-	2	-	-	2-3
Alkalinity	54	-	-	-	-	134	-	-	-	-	-	-	64	-	-	54-134
Metallic Micronutrients																
Boron (T)	0.0	-	-	-	-	0.1	-	-	-	-	-	-	0.0	-	-	0.0-0.1
Copper (T)	-	0.018	0.031	0.035	0.033	0.061	0.015	0.017	0.019	0.008	0.008	0.009	0.007	0.004	0.008	0.004-0.061
Iron (T)	-	0.436	0.787	1.87	1.63	0.708	0.392	0.492	1.50	1.40	1.04	1.40	0.920	0.240	0.378	0.378-1.87
Manganese (T)	-	0.771	1.06	1.10	1.24	1.02	0.894	0.234	0.322	0.125	0.058	0.178	0.236	0.098	0.920	0.058-1.24
Zinc (T)	-	-	-	-	-	0.002	-	-	-	-	-	-	0.005	-	-	0.002-0.005
Other Metals																
Aluminum (T)	0.695	-	-	-	-	0.178	-	-	-	-	-	-	0.380	-	-	0.178-0.695
Arsenic (T)	-	-	-	-	-	0.0027	-	-	-	-	-	-	0.0014	-	-	0.0014-0.0027
Cadmium (T)	-	-	-	-	-	0.000	-	-	-	-	-	-	0.000	-	-	0.000
Chromium (T)	-	-	-	-	-	0.002	-	-	-	-	-	-	0.005	-	-	0.002-0.005
Lead (T)	-	-	-	-	-	0.00	-	-	-	-	-	-	0.00	-	-	0.00
Mercury (T)	-	-	-	-	-	0.0003	-	-	-	-	-	-	0.0000	-	-	0.0000-0.0003
Selenium (T)	-	-	-	-	-	0.0000	-	-	-	-	-	-	0.0003	-	-	0.0000-0.0003

Note: T = total, D = dissolved

Table 2c. Laboratory analyses results (in mg/L) for water collected from Davis Creek near Morris Reservoir.

	4/24/86	5/21/86	6/18/86	7/09/86	8/07/86	9/11/86	10/10/86	11/06/86	12/11/86	1/09/87	2/05/87	3/04/87	4/03/87	5/07/87	6/05/87	Range
Nitrogen																
Nitrate plus Nitrite (T)	0.00	0.00	0.00	0.00	0.02	0.01	0.02	0.01	0.01	0.01	0.00	<0.01	<0.01	<0.01	<0.01	0.00-0.02
Ammonia (T)	0.00	0.00	0.00	0.00	0.01	0.01	0.02	0.12	0.10	0.01	0.02	<0.01	<0.01	<0.01	<0.01	0.00-0.12
Organic Nitrogen (T)	0.1	0.1	0.1	0.2	0.2	0.1	0.0	0.2	0.2	0.0	0.1	<0.1	<0.1	<0.1	<0.1	0.0-0.2
Phosphorus																
Phosphorus (T)	0.00	0.02	0.02	0.04	0.03	0.04	0.03	0.11	0.08	0.02	0.01	0.01	0.01	0.02	0.02	0.00-0.11
Orthophosphate (D)	0.00	0.00	0.01	0.00	0.02	0.01	0.01	0.00	0.00	0.00	0.00	<0.01	<0.01	0.01	0.01	0.00-0.02
Sulfur																
Sulfate (D)	11	12	11	12	14	15	15	14	15	12	9	10	8	12	13	8-15
Salinity																
Calcium (D)	38	39	42	44	43	44	47	47	46	34	26	32	29	38	38	26-47
Magnesium (D)	9	9	10	10	10	10	11	11	12	8	7	8	8	9	9	7-12
Hardness (D)	132	135	146	151	148	151	162	162	165	118	94	113	106	132	132	94-165
Sodium (D)	7	-	-	-	-	8	-	-	8	-	-	-	5	7	7	5-8
Potassium (D)	1.2	-	-	-	-	1.4	-	-	1.1	-	-	-	0.7	1.2	1.1	0.7-1.4
Chloride (D)	2	-	-	-	-	3	-	-	-	-	-	-	2	-	-	2-3
Alkalinity	126	-	-	-	-	153	-	-	-	-	-	-	102	-	-	102-153
Metallic Micronutrients																
Boron (T)	0.0	-	-	-	-	0.1	-	-	-	-	-	-	0.00	-	-	0.0-0.1
Copper (T)	0.003	0.006	0.004	0.004	0.005	0.004	0.002	0.001	0.001	0.001	0.000	0.001	0.000	0.000	0.000	0.000-0.006
Iron (T)	0.033	0.066	0.043	0.072	0.054	0.068	0.063	1.34	1.12	0.040	0.092	0.074	0.067	0.053	0.028	0.028-1.34
Manganese (T)	0.005	0.011	0.013	0.014	0.016	0.016	0.016	0.732	0.620	0.004	0.002	0.005	0.006	0.002	0.010	0.002-0.732
Zinc (T)	0.002	-	-	-	-	0.005	-	-	-	-	-	-	0.001	-	-	0.001-0.005
Other Metals																
Aluminum (T)	0.020	-	-	-	-	0.031	-	-	-	-	-	-	0.121	-	-	0.020-0.121
Arsenic (T)	0.0004	-	-	-	-	0.0008	-	-	-	-	-	-	0.0000	-	-	0.0000-0.0008
Cadmium (T)	0.000	-	-	-	-	0.000	-	-	-	-	-	-	0.000	-	-	0.000
Chromium (T)	0.002	-	-	-	-	0.001	-	-	-	-	-	-	0.001	-	-	0.001-0.002
Lead (T)	0.00	-	-	-	-	0.00	-	-	-	-	-	-	0.00	-	-	0.00
Mercury (T)	0.0002	-	-	-	-	0.0001	-	-	-	-	-	-	0.0000	-	-	0.0000-0.0002
Selenium (T)	0.0000	-	-	-	-	0.0000	-	-	-	-	-	-	0.0000	-	-	0.0000

Note: T = total, D = dissolved

Table 2d. Laboratory analyses results (in mg/L) for water collected from an unnamed middle tributary near Morris Reservoir.

	4/24/86	1/09/87	2/05/87	3/04/87	4/03/877	Range
Nitrogen						
Nitrate plus Nitrite (T)	0.02	0.02	0.01	<0.01	<0.01	<0.01-0.02
Ammonia (T)	0.01	0.01	0.03	<0.01	<0.01	<0.01-0.03
Organic Nitrogen (T)	0.0	0.2	0.2	0.1	<0.1	0.0-0.2
Phosphorus						
Phosphorus (T)	0.00	0.02	0.03	0.01	0.01	0.00-0.03
Orthophosphate (D)	0.00	0.01	0.01	<0.01	<0.01	0.00-0.01
Sulfur						
Sulfate (D)	3	7	4	6	5	3-7
Salinity						
Calcium (D)	10	8	7	8	9	7-10
Magnesium (D)	6	5	5	5	6	5-6
Hardness (D)	50	40	38	40	47	38-50
Sodium (D)	5	-	-	-	5	5
Potassium (D)	0.8	-	-	-	0.5	0.5-0.8
Chloride (D)	5	-	-	-	3	3-5
Alkalinity	43	-	-	-	47	43-47
Metallic Micronutrients						
Boron (T)	0.1	-	-	-	0.0	0.1
Copper (T)	0.005	0.003	0.003	0.003	-	0.003-0.005
Iron (T)	0.178	0.464	0.680	0.214	-	0.178-0.680
Manganese (T)	0.019	0.005	0.007	0.004	0.005	0.005-0.019
Zinc (T)	0.004	-	-	-	0.002	0.002-0.004
Other Metals						
Aluminum (T)	0.089	-	-	-	0.054	0.054-0.089
Arsenic (T)	0.0001	-	-	-	0.0000	0.0000-0.0001
Cadmium (T)	0.000	-	-	-	0.000	0.000
Chromium (T)	0.002	-	-	-	0.002	0.002
Lead (T)	0.00	-	-	-	0.00	0.00
Mercury (T)	0.0001	-	-	-	0.0001	0.0001
Selenium (T)	0.0000	-	-	-	0.0000	0.0000

Note: T = total, D = dissolved

Table 2e. Laboratory analyses results (in mg/L) for water collected from an unnamed east tributary near Morris Reservoir.

	4/24/86	5/21/86	6/18/86	1/09/87	2/05/87	3/04/87	4/03/87	5/07/87	Range
Nitrogen									
Nitrate plus Nitrite (T)	0.00	0.00	0.00	0.01	0.00	<0.01	<0.01	<0.01	0.00-0.01
Ammonia (T)	0.00	0.00	0.00	0.02	0.02	<0.01	<0.01	<0.01	0.00-0.02
Organic Nitrogen (T)	0.0	0.1	0.1	0.1	0.2	0.1	<0.1	0.1	0.0-0.2
Phosphorus									
Phosphorus (T)	0.00	0.01	0.01	0.01	0.02	<0.01	<0.01	<0.01	0.00-0.02
Orthophosphate (D)	0.00	0.00	0.00	0.00	0.00	<0.01	<0.01	<0.01	0.00-<0.01
Sulfur									
Sulfate (D)	4	6	7	5	3	4	2	7	2-7
Salinity									
Calcium (D)	10	10	13	8	8	10	9	12	8-13
Magnesium (D)	7	8	10	6	6	7	7	9	6-10
Hardness (D)	54	58	74	44	44	54	52	67	44-74
Sodium (D)	4	-	-	-	-	-	4	5	4-5
Potassium (D)	0.7	-	-	-	-	-	0.3	0.7	0.3-0.7
Chloride (D)	3	-	-	-	-	-	3	-	3
Alkalinity	49	-	-	-	-	-	52	-	49-52
Metallic Micronutrients									
Boron (T)	0.0	-	-	-	-	-	0.0	-	0.0
Copper (T)	-	0.006	0.004	0.001	0.002	0.003	0.001	0.001	0.001-0.006
Iron (T)	-	0.084	0.045	0.052	0.432	0.296	0.136	0.027	0.027-0.432
Manganese (T)	-	0.003	0.002	0.003	0.006	0.003	0.002	0.000	0.000-0.006
Zinc (T)	-	-	-	-	-	-	0.002	-	0.002
Other Metals									
Aluminum (T)	0.037	-	-	-	-	-	0.066	-	0.037-0.066
Arsenic (T)	-	-	-	-	-	-	0.0000	-	0.0000
Cadmium (T)	-	-	-	-	-	-	0.000	-	0.000
Chromium (T)	-	-	-	-	-	-	0.003	-	0.003
Lead (T)	-	-	-	-	-	-	0.00	-	0.00
Mercury (T)	-	-	-	-	-	-	0.0000	-	0.0000
Selenium (T)	-	-	-	-	-	-	0.0000	-	0.0000

Note: T = total, D = dissolved

Table 2f. Laboratory analyses results (in mg/L) for water collected from the raw water tap at the Water Treatment Plant.

	5/21/86	6/18/86	7/09/86	8/07/86	9/12/86	10/10/86	11/06/86	12/11/86	1/09/87	2/05/87	3/05/87	4/02/87	5/07/87	6/05/87	Range
Nitrogen															
Nitrate plus Nitrite (T)	0.01	0.01	0.07	0.04	0.14	0.24	0.05	0.05	0.06	0.01	<0.01	0.02	0.07	0.01	<0.01-0.24
Ammonia (T)	0.01	0.10	0.06	0.16	0.04	0.10	0.02	0.01	0.04	0.03	0.01	<0.01	0.04	0.10	<0.01-0.16
Organic Nitrogen (T)	0.3	0.2	0.7	0.6	0.7	0.4	0.4	0.4	0.4	0.3	0.3	0.1	0.1	0.4	0.1-0.7
Phosphorus															
Phosphorus (T)	0.03	0.07	0.07	0.07	0.13	0.04	0.05	0.04	0.05	0.04	0.03	0.02	0.04	0.06	0.02-0.13
Orthophosphate (D)	0.00	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.01	<0.01	<0.01	0.01	0.02	0.00-0.02
Sulfur															
Sulfate (D)	6	5	6	7	10	11	11	12	9	7	5	3	4	4	3-12
Salinity															
Calcium (D)	20	21	26	32	37	38	40	41	22	14	14	14	16	16	14-41
Magnesium (D)	6	7	8	9	10	10	11	12	6	6	5	5	5	5	5-12
Hardness (D)	74	82	98	117	134	136	145	152	80	60	56	56	60	60	56-152
Sodium (D)	4	-	-	-	7	-	-	8	-	-	-	4	4	4	4-8
Potassium (D)	1.0	-	-	-	1.4	-	-	1.4	-	-	-	0.6	0.8	0.7	0.6-1.4
Chloride (D)	2	-	-	-	3	-	-	-	-	-	-	2	-	-	2-3
Alkalinity	78	-	-	-	135	-	-	-	-	-	-	58	-	-	58-135
Metallic Micronutrients															
Boron (T)	0.0	-	-	-	0.1	-	-	-	-	-	-	0.0	-	-	0.0-0.1
Copper (T)	-	0.042	0.075	0.092	0.085	0.091	0.117	0.047	0.019	0.024	0.033	0.022	0.047	0.042	0.019-0.117
Iron (T)	-	0.235	0.161	0.440	0.552	0.308	0.376	0.322	1.26	1.24	1.1	0.908	0.139	0.492	0.139-1.26
Manganese (T)	-	0.430	0.241	1.13	0.238	0.181	0.286	0.110	0.094	0.034	0.045	0.003	0.048	0.520	0.003-1.13
Zinc (T)	-	-	-	-	0.012	-	-	-	-	-	-	0.008	-	-	0.008-0.012
Other Metals															
Aluminum (T)	0.081	-	-	-	0.144	-	-	-	-	-	-	0.416	-	-	0.081-0.416
Arsenic (T)	-	-	-	-	0.0015	-	-	-	-	-	-	0.0000	-	-	0.0000-0.0015
Cadmium (T)	-	-	-	-	0.000	-	-	-	-	-	-	0.000	-	-	0.000
Chromium (T)	-	-	-	-	0.003	-	-	-	-	-	-	0.005	-	-	0.003-0.005
Lead (T)	-	-	-	-	0.00	-	-	-	-	-	-	0.00	-	-	0.00
Mercury (T)	-	-	-	-	0.0001	-	-	-	-	-	-	0.0001	-	-	0.0001
Selenium (T)	-	-	-	-	0.0000	-	-	-	-	-	-	0.0000	-	-	0.0000

Note: T = total, D = dissolved

Table 2g. Laboratory analyses results (in mg/L) for water collected from the hypolimnetic pump at Morris Dam.

	7/09/86	8/07/86	Range
Nitrogen			
Nitrate plus Nitrite (T)	0.01	0.01	0.01
Ammonia (T)	0.10	0.16	0.10-0.16
Organic Nitrogen (T)	0.7	0.7	0.7
Phosphorus			
Phosphorus (T)	0.05	0.06	0.05-0.06
Orthophosphate (D)	0.01	0.02	0.01-0.02
Sulfur			
Sulfate (D)	-	6	6
Salinity			
Calcium (D)	-	31	31
Magnesium (D)	-	8	8
Hardness (D)	-	111	111
Sodium (D)	-	-	-
Potassium (D)	-	-	-
Chloride (D)	-	-	-
Alkalinity	-	-	-
Metallic Micronutrients			
Boron (T)	-	-	-
Copper (T)	-	0.050	0.050
Iron (T)	-	0.323	0.323
Manganese (T)	-	0.471	0.471
Zinc (T)	-	-	-
Other Metals			
Aluminum (T)	-	-	-
Arsenic (T)	-	-	-
Cadmium (T)	-	-	-
Chromium (T)	-	-	-
Lead (T)	-	-	-
Mercury (T)	-	-	-
Selenium (T)	-	-	-

Note: T = total, D = dissolved

levels than in the epilimnion. The treatment plant and hypolimnetic pump draw water from this zone. Complete decomposition of organic materials settling from upper layers into the hypolimnion diminishes the oxygen supply. Aerobic decomposition occurs in the hypolimnion from late fall to late spring because at least some level of oxygenation is maintained through mixing of surface and bottom waters by winds. However, thermal stratification during the summer prevents mixing of lower strata with the upper oxygenated layer. Depletion of the oxygen supply by mid-summer results in anaerobic decomposition of organic materials. While aerobic decomposition results in production of ammonia, nitrite, and nitrate, anaerobic decomposition produces ammonia and nitrogen gas. Some ammonia is lost to the bottom sediments through sorption, but ammonia is returned to the water through leaching. Nitrogen gas is lost from the hypolimnion by the formation of bubbles that rise to the surface and by anaerobic nitrogen fixation by bacteria in the sediments. Organic materials that settle or are produced in the sediments decompose anaerobically to produce ammonia through the process of ammonification or may form organic deposits that resist decomposition. Soluble nitrogen of the hypolimnion becomes mixed throughout the water column following breakdown of thermal stratification in late fall. Aeration results in conversion of much of the ammonia to nitrite and nitrate, which is then available for primary production of organic materials (algae).

Phosphorus. Phosphorus occurs in natural waters primarily as phosphates. Inorganic phosphates occur as orthophosphates and condensed phosphates (pyro-, meta-, and other polyphosphates), but orthophosphates are the only significant form in natural waters. Most of the phosphates present in water are bound organically, primarily in algae (Wetzel, 1975). Phosphorus is an essential nutrient required by all plants, but is often present in growth-limiting quantities. Phosphorus has most often been the nutrient identified as limiting algal growth in lakes. Total phosphorus concentrations in most lakes range from 0.01 to 0.05 mg/L. Eutrophic lakes typically have epilimnetic total phosphorus concentrations from 0.03 to 0.10 mg/L. Clear Lake could be classified as hypereutrophic, based on total phosphorus concentrations that range up to 0.55 mg/L (Gaonker, 1971). Orthophosphate concentrations in Clear Lake range from 0.01 to 0.46 mg/L.

Total phosphorus concentrations from Morris Reservoir ranged from less than 0.01 to 0.05 mg/L at the surface and 0.03 to 0.18 mg/L at the bottom (Table 2). Total phosphorus levels at the surface were rather evenly distributed throughout the study period, but at the bottom were significantly elevated from June through October. Total phosphorus concentrations in the tributaries ranged up to 0.04 mg/L, except that 0.11 and 0.08 mg/L were found during November and December, respectively, when Davis Creek was sampled below the normally flooded, organically rich delta. Total phosphorus concentrations ranged at the treatment plant from 0.02 to 0.13 mg/L, and at the hypolimnetic pump from 0.05 to 0.06 mg/L.

Dissolved orthophosphate was present at very low levels at all sampling locations. Concentrations of dissolved orthophosphate in Morris Reservoir ranged from 0.00 to 0.01 mg/L at the surface and 0.00 to 0.03 mg/L at the bottom. Concentrations in the tributaries, treatment plant, and hypolimnetic pump ranged from 0.00 to 0.02 mg/L.

The meso-eutrophic status of Morris Reservoir results in abundant algal growth, with most of the phosphorus bound organically. Algal production in the epilimnion is maintained through efficient recycling of orthophosphate. Orthophosphate produced by secretions from algae, excretory products of zooplankton, and decomposition of organic materials including decaying algae is rapidly assimilated by growing algae so that little free orthophosphate may be present. Dissolved orthophosphate levels determined from surface and bottom waters in Morris Resevoir do not represent all orthophosphate present. Suspended materials interfere with the colorimetric determination of orthophosphate, thus necessitating sample filtration. However, filtration removes from analyses the suspended orthophosphate as well as some unknown fraction of dissolved orthophosphate through adsorption. Aeration during filtration of anaerobic water samples collected from the bottom of Morris Reservoir results in the oxidation of ferrous ions to ferric ions and precipitation of ferric phosphate and ferric hydroxide with adsorbed orthophosphate. Both precipitates decrease the concentration of dissolved orthophosphate in the sample container. Total phosphorus levels provide a better representation of phosphorus dynamics in Morris Reservoir. Total phosphorus concentrations in the hypolimnion increase significantly during summer stratification as organic materials settle to the bottom and phosphorus is regenerated from the sediments by desorbtion and dissolution of primarily iron and manganese compounds under anaerobic conditions. The fall turnover results in redistribution of phosphorus throughout the water column.

Sulfur. The predominant form of sulfur in natural waters is sulfate, which normally occurs in lakes at concentrations ranging from 3 to 30 mg/L (Hutchinson, 1957). Sulfate generally occurs in waters in much higher concentrations than needed for protein synthesis in both photosynthetic and animal metabolism. Assimilation of sulfate into organic biomass is followed in the sulfur cycle by decomposition to hydrogen sulfide (H_2S) or sedimentation as organic sulfur (Figure 6). Hydrogen sulfide is rapidly oxidized to sulfate under aerobic conditions, but persists under anaerobic conditions where it enters into reactions affecting the cycling of other nutrients and metals.

Sulfate concentrations from the surface of Morris Reservoir varied from 5 to 12 mg/L (Table 2). Concentrations of sulfate from the bottom waters of the reservoir had a similar range (4 to 12 mg/L), but were significantly lower than surface concentrations during the spring and summer when the hypolimnion was anoxic. Anaerobic decomposition of organic materials in the hypolimnion had converted some of the organic sulfate to hydrogen sulfide, as evidenced by the detectable odor from water samples. Following aeration from the onset of lake turnover in September, hydrogen sulfide was oxidized to sulfate and concentrations were similar between the epilimnion and hypolimnion. Sulfate concentrations in Davis Creek were slightly higher than those in the reservoir, ranging from 9 to 15 mg/L. The concentrations in the other two tributaries ranged from 3 to 7 mg/L. Sulfate concentrations at the treatment plant (5 to 12 mg/L) and the hypolimnetic pump (6 mg/L) indicate the presence of anaerobic conditions at the withdrawal elevations in Morris Reservoir, with lower sulfate concentrations than reservoir surface waters and the detectable odor of hydrogen sulfide.

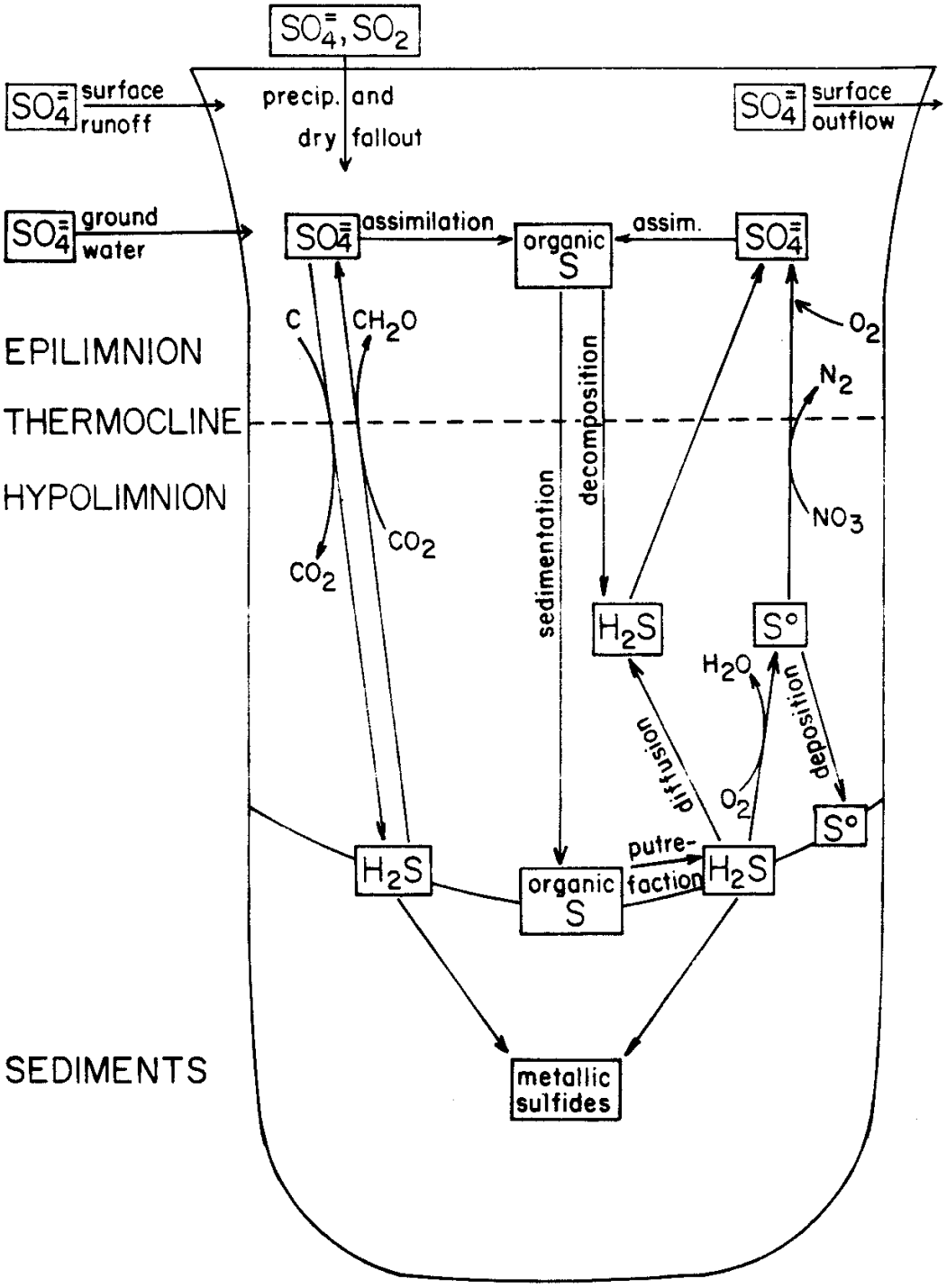

Figure 6. General sulfur cycle for freshwater lakes. (Modified from Wetzel, 1975.)

Salinity. Total salinity of inland waters is dominated, in decreasing order, by the cations calcium, magnesium, sodium, and potassium, and the anions carbonate, sulfate, and chloride (Wetzel, 1975). Magnesium, sodium, potassium, and chloride undergo relatively minor fluctuations in concentrations in lakes as a result of biotic utilization, while calcium, carbonate, and sulfate can undergo rather large fluctuations due to microbial metabolism. Calcium and magnesium are primarily reponsible for determination of water hardness, which affects the toxicity of metals to aquatic biota. Soft waters have a hardness, expressed as milligrams per liter of calcium carbonate (mg/L as $CaCO_3$), of from 0 to 75. Moderately hard waters range from 75 to 150 mg/L as $CaCO_3$, while hard and very hard waters range from 150 to 300 and greater than 300 mg/L as $CaCO_3$, respectively (USEPA, 1986).

The elements associated with salinity are required nutrients of plants, but are usually present in fresh waters in large excess in relation to their requirements. Calcium is required for the maintenance of cell membranes in ion absorption and retention. Magnesium is part of the chlorophyll molecule, and is involved in enzymatic reactions. Sodium and potassium are primarily involved in ion transport and exchange. The threshold sodium level required for near optimal growth of several blue-green algae is 4 mg/L, while optimal growth occurs at 40 mg/L (Wetzel, 1975). Chloride is influential in general osmotic salinity balance and ion exchange. Monovalent-divalent ion (chiefly magnesium and calcium) ratios less than 1.5 usually favor diatom algae, while ratios much greater than 1.5 usually favor desmid algae.

Calcium concentrations from the surface of Morris Reservoir ranged from 12 to 42 mg/L and were generally at higher levels than in the hypolimnion, which ranged from 13 to 48 mg/L, during the spring and summer, but at slightly lower levels during the fall and winter (Table 2). Calcium distributions in Morris Reservoir are the result of precipitation and dissolution reactions with various anions and humic acids that differ temporally and spatially, as well as the inflow of Davis Creek, which had calcium concentrations ranging from 26 to 47 mg/L. Concentrations of calcium in the other two tributaries ranged up to 13 mg/L. Calcium concentrations at the treatment plant and the hypolimnetic pump reflected the concentrations of calcium in the water at the level of withdrawal and were intermediate between surface and bottom concentrations.

Magnesium concentrations followed the same pattern as calcium at the various stations. Magnesium levels from Morris Reservoir ranged from 5 to 12 mg/L at the surface and 5 to 11 mg/L at the bottom. Levels in Davis Creek ranged from 7 to 12 mg/L and up to 10 mg/L in the other two tributaries. Water at the treatment plant had magnesium concentrations ranging from 5 to 12 mg/L. A sample from the hypolimnetic pump during August produced a magnesium concentration of 8 mg/L.

Water hardness, reflecting calcium and magnesium concentrations, increased during the spring to a peak level in early winter and subsequently declined at all monitoring locations. Hardness ranged from 50 to 155 and 53 to 165 mg/L as $CaCO_3$ at the surface and bottom, respectively, of Morris Reservoir. Hardness in Davis Creek ranged from 94 to 165 mg/L as $CaCO_3$, while the other two tributaries ranged up to 74 mg/L as $CaCO_3$. Hardness at the treatment plant and hypolimnetic pump reflected the water quality at the withdrawal elevation, with values of 56 to 152 and 111 mg/L as $CaCO_3$, respectively. Based on the

measured levels, water in Morris Reservoir can be classified as soft during the late winter to early spring periods and moderately hard from late spring to early winter. Davis Creek remained moderately hard the entire year, while the two tributaries are classified as soft. Water at the treatment plant was soft in late winter and increased in hardness the rest of the year, reaching a maximum moderately hard condition in early winter.

Sodium concentrations were similar at the surface and bottom of Morris Reservoir, ranging from 5 to 8 and 4 to 8 mg/L, respectively. Sodium concentrations ranged from 7 to 8 mg/L in Davis Creek, but were slightly lower in the other tributaries. The sodium concentrations at the treatment plant reflected those in the reservoir and ranged from 4 to 8 mg/L.

Potassium and chloride levels were also similar at the surface and bottom of Morris Reservoir. Potassium concentrations ranged from 1.0 to 1.5 mg/L at the surface and 0.9 to 1.4 mg/L at the bottom. Chloride concentrations from both the surface and bottom ranged from 2 to 3 mg/L. Potassium concentrations were higher in Davis Creek than the other two tributaries, ranging from 1.1 to 1.4 and 0.7 to 0.8 mg/L, respectively, while chloride levels were lower in Davis Creek than the tributaries, ranging from 2 to 3 and 3 to 5 mg/L, respectively. Potassium and chloride concentrations at the treatment plant ranged from 1.0 to 1.4 and 2 to 3 mg/L, respectively.

Alkalinity. Alkalinity is a measure of the buffering capacity of water to resist a change in pH and is usually governed by carbon dioxide-bicarbonate-carbonate (CO_2-HCO_3-CO_3) equilibrium. Buffering waters against wide fluctuations in pH is important for maintaining aquatic life. Alkalinity levels between 100 and 120 mg/L or more of $CaCO_3$ are generally recognized as best for supporting diversified aquatic life (McKee and Wolf, 1963), while levels up to about 400 mg/L as $CaCO_3$ are not considered harmful to human health (USEPA, 1986). Alkalinity is measured by titration with standardized acid to a pH of 4.5 and is commonly expressed as mg/L of $CaCO_3$ (USEPA, 1986).

Alkalinity ranged from 85 to 134 mg/L as $CaCO_3$ at the surface of Morris Reservoir and 54 to 134 mg/L as $CaCO_3$ at the bottom (Table 2). Alkalinity was higher in Davis Creek, ranging from 126 to 153 mg/L as $CaCO_3$. The other two tributaries had alkalinity levels during the spring of 43 and 49 mg/L as $CaCO_3$. Alkalinity at the treatment plant reflects that of the withdrawal elevation in the lake and ranged from 78 to 135 mg/L as $CaCO_3$.

Metallic Micronutrients. Several of the minor metallic elements, including boron, copper, iron, manganese, and zinc, are required in trace amounts for algal growth. However, in larger quantities these elements become inhibitory or toxic to algae and other aquatic organisms. The concentrations of metallic ions in aerated surface waters are generally very low, but availability is increased by complexing with chelating agents of various organic materials. Iron and manganese concentrations in the hypolimnion during summer stratification are strongly related to oxidation-reduction (redox) processes, while accumulations of the other metallic species are largely related to release from decomposing settling organic materials.

Boron has been found in lakes in the United States at concentrations up to 5 mg/L, but the average concentration was only 0.1 mg/L (USEPA, 1986).

Water is suitable for domestic uses with boron concentrations up to 30 mg/L. Sensitive fish have shown no adverse effects to boron concentrations of 19,000 to 19,500 mg/L. Sensitive crops, however, have exhibited toxic symptoms to boron concentrations of less than 1 mg/L. A criterion of 0.75 mg/L has been established for long-term irrigation on sensitive crops.

Copper normally occurs in surface waters in only trace amounts since cupric ions quickly precipitate as hydroxides or carbonates at pH values greater than 7. Copper renders water organoleptically unacceptable at levels far below those demonstrated to cause health effects. Threshold concentrations for taste occur in the range of 1.0 to 2.0 mg/L of copper, while concentrations of 5 to 7.5 mg/L make water completely undrinkable (McKee and Wolf, 1963). Effects of copper concentrations on aquatic life vary with water hardness, species of organism, and synergistic effects with other metals. Acute and chronic levels of copper (in micrograms per liter) that should produce no adverse effects to most aquatic organisms are calculated from the formulas $e^{(0.9422\ [\ln(\text{hardness})]-1.464)}$ and $e^{(0.8545\ [\ln(\text{hardness})]-1.465)}$, respectively (USEPA, 1986). At hardnesses of 50, 100, and 200 mg/L as $CaCO_3$, the acute and chronic acceptable cooper levels would be 9.2, 18, and 34 ug/L and 6.5, 12, and 21 ug/L, respectively. Copper sulfate is widely used to control nuisance growths of algae in water supply reservoirs. Though susceptibility varies, most algae are controlled at a copper sulfate concentration of 1.0 mg/L (0.25 mg/L of copper). A maximum contaminant limit of 1.0 mg/L of copper has been established based on consumer acceptance (DHS, 1977).

Iron occurs in natural waters as ferrous and ferric ions. Ferrous ions are rapidly oxidized in oxygenated surface waters to ferric ions, which form the insoluble ferric hydroxide. Other ions, especially orthophosphate, adsorb to ferric hydroxide and co-precipitate to the hypolimnion. Anaerobic reduction in the hypolimnion causes dissolution of ferric hydroxide, with conversion of ferric ions to ferrous ions and the release of adsorbed ions. Relatively high concentrations of iron in drinking water have no adverse health effects, but unpalatable tastes are sometimes produced in water at iron concentrations as low as 0.1 to 0.2 mg/L (McKee and Wolf, 1963). Ferric hydroxide causes staining of laundry and porcelain fixtures at relatively low concentrations. Levels of iron normally encountered in surface waters do not adversely affect aquatic life. An acceptance limit of 0.3 mg/L is based on aesthetics and taste considerations (DHS, 1977).

Manganese occurs as manganous and manganic ions in natural surface waters. Like iron, manganous ions are rapidly oxidized to insoluble manganic ions under aerobic conditions, which precipitate as oxides, carbonates, or hydroxides to the hypolimnion. Anaerobic conditions cause the precipitates to dissociate, releasing soluble manganous ions. Concentrations of manganese normally encountered in surface waters do not cause adverse health effects. Unacceptable staining of laundry and objectionable tastes occur as manganese concentrations in drinking water approach 0.150 mg/L (USEPA, 1986). The presence of iron may intensify the adverse effects of manganese. Conventional treatment of domestic water supplies is largely ineffective in removing manganese. Aquatic life is not adversely affected by levels of manganese normally encountered in surface waters. An acceptance limit of 0.05 mg/L of manganese is based on aesthetic and taste considerations (DHS, 1977).

Zinc is present in most natural waters in only trace amounts. Unpalatable tastes occur at zinc concentrations much less than those that would cause adverse health effects. Toxicity of zinc to aquatic life is affected by water hardness, species of organism, and synergistic effects of other metals. Acute and chronic levels of zinc that should not be exceeded to protect aquatic life are $e^{(0.83[\ln(\text{hardness})] + 1.95)}$ and 47 ug/L, respectively (USEPA, 1986). At hardness of 50, 100 and 200 mg/L as $CaCO_3$, acceptable acute zinc concentrations would be 180, 320, and 570 ug/L. A maximum acceptance limit of 5.0 mg/L of zinc is based on taste and odor considerations (DHS, 1977).

Boron concentrations from Morris Reservoir and the three tributaries were at similar levels (Table 2). Concentrations ranged up to 0.1 mg/L, equivalent to average levels found from other waters in the United States. No water quality impairment due to boron levels is indicated for the Morris Reservoir watershed.

Copper levels from the surface of Morris Reservoir were highly variable, reflecting natural low inputs from tributaries during the winter and early spring, and artificial addition of copper sulfate at random intervals from late spring to early fall. Copper levels from the bottom of Morris Reservoir were less variable, but exhibited a significant increase during the summer months as cupric hydroxides precipitated and organically bound copper settled to the bottom. Organically bound copper is released through bacterial decomposition, but much of the inorganic copper becomes immobilized at the surface of the muds as cuprous sulfide under anaerobic conditions. Copper concentrations in Morris Reservoir ranged from 0.005 to 0.166 mg/L at the surface and 0.004 to 0.061 mg/L at the bottom. Copper levels from Morris Reservoir were well below those causing unacceptable tastes, but routinely exceeded criteria for the protection of aquatic life primarily during the period of copper sulfate treatment for algae control from late spring to early fall (Table 3). Copper levels in the tributaries were at low levels, ranging up to 0.006 mg/L, and did not exceed the criteria for protection of aquatic life. Copper levels in water from the treatment plant and hypolimnetic pump were intermediate between those of the surface and bottom of Morris Reservoir from late spring to early fall, reflecting the settling of organic and inorganic forms of copper. However, copper levels at the treatment plant were significantly greater than those of either the surface or bottom waters of the reservoir during late winter and early spring when reservoir waters should be uniformly mixed, possibly reflecting resolubilization of copper sedimented in the pipeline or leaching from the copper tubing that supplies water to the raw water tap at the treatment plant.

Iron concentrations from Morris Reservoir ranged from 0.043 to 1.54 mg/L at the surface and 0.378 to 1.87 mg/L at the bottom. Iron levels were higher from the bottom during the summer due to resolubilization of ferrous ions following anaerobic reduction of ferric hydroxide from the bottom sediments. Iron levels from the bottom decreased slightly during mid-summer, which may be due to iron precipitation to the sediments in the form of insoluble ferrous sulfide as hydrogen sulfide developed during anaerobic decomposition of organic materials. Surface iron levels increased slightly in mid-summer as the deepening thermocline allowed mixing of surface waters with iron-rich waters from deeper depths. Erosion of the thermocline from the early stages of destratification beginning in late summer allowed increased mixing of

Table 3. Copper levels and criteria for protection of aquatic life in Morris Reservoir.

Date	Surface		Criteria[1/]		Bottom		Criteria[1/]	
	Copper (ug/L)	Hardness (mg/L as $CaCO_3$)	Acute[2/] (ug/L)	Chronic[3/] (ug/L)	Copper (ug/L)	Hardness (mg/L as $CaCO_3$)	Acute[2/] (ug/L)	Chronic[3/] (ug/L)
4/24/86	-	89	16	11	-	53	10	7
5/21/86	77	98	17	12	18	70	13	9
6/18/86	25	106	19	12	31	70	13	9
7/09/86	150	115	20	13	35	84	15	10
8/07/86	140	122	21	14	33	108	19	12
9/11/86	52	136	24	15	61	134	24	15
10/10/86	166	136	24	15	15	136	24	15
11/06/86	15	145	25	16	17	165	28	18
12/11/86	8	155	27	17	19	152	26	17
1/09/87	9	80	14	10	8	86	15	10
2/05/87	6	50	9	7	8	74	13	9
3/04/87	10	56	10	7	9	70	13	9
4/03/87	5	-	-	-	7	-	-	-
5/07/87	-	-	-	-	-	-	-	-
6/05/87	-	-	-	-	-	-	-	-

1/ USEPA, 1986

2/ $e^{(0.9422[\ln(\text{hardness})]-1.464)}$

3/ $e^{(0.8545[\ln(\text{hardness})]-1.465)}$

surface waters and those from deeper strata with concomitant increases in iron levels from the surface. Complete destratification and mixing by early fall resulted in a more even distribution of iron in surface and bottom waters, though iron levels remained higher in the bottom of the reservoir due to precipitation and settling of ferric hydroxide under aerobic conditions. Occasional mixing of the water column by wind action during the winter maintained surface iron concentrations by resuspension of the ferric hydroxide precipitate from deeper depths and bottom sediments. The reservoir serves as a settling basin for iron contributed by the tributaries. Iron levels in Davis Creek ranged from 0.028 to 1.34 mg/L. The other two tributaries contained iron concentrations ranging from 0.027 to 0.432 mg/L and 0.178 to 0.680 mg/L. Surface runoff following storms in November and December caused iron concentrations to increase by twenty times that normally present. Iron levels from the treatment plant and hypolimnetic pump were intermediate between levels from the reservoir surface and bottom. The criterion for prevention of aesthetic and taste problems due to iron was exceeded every month except June and July at the treatment plant.

Manganese concentrations followed a pattern similar to that of iron. Concentrations of manganese ranged from 0.008 to 0.236 mg/L at the surface and 0.058 to 1.24 mg/L at the bottom of Morris Reservoir. Manganese concentrations were higher at the bottom during much of the year due to resolubilization of manganous ions under anaerobic conditions during the summer, and precipitation of manganic ions following destratification and aeration through mixing of the water column during fall and winter. Manganese levels ranged from 0.002 to 0.732 mg/L in Davis Creek, and 0.005 to 0.019 mg/L and 0.000 to 0.006 mg/L in the other two tributaries. Manganese levels in Davis Creek increased beyond that normally found by about forty times following storms in November and December. Manganese levels at the treatment plant and hypolimnetic pump generally reflect levels found in Morris Reservoir intermediate between surface and bottom. Manganese concentrations at the treatment plant exceeded the criterion for prevention of aesthetic and taste problems in all months except February, March, and April of 1987. Manganese concentrations exceeded those known to result in objectionable tastes and staining of laundry during June through November.

Zinc was present in trace quantities from each of the monitoring locations. Concentrations ranged from 0.004 to 0.007 mg/L and 0.002 to 0.005 mg/L at the surface and bottom, respectively, of Morris Reservoir and up to 0.005 mg/L in the tributaries. Zinc levels at the treatment plant were slightly higher than at the reservoir and ranged from 0.008 to 0.012 mg/L. Zinc concentrations were well below criteria for protection of aquatic life and prevention of taste and odor problems at every monitoring location.

Other Metals. Several metallic elements, which are not generally required for the growth of algae, may impair the quality of water for beneficial uses. Those elements most frequently encountered include arsenic, cadmium, chromium, lead, mercury, and selenium. Aluminum is also included because of the use of aluminum sulfate (alum) in water treatment plants and the potential to interfere with nutrient availability to algae.

Aluminum is one of the most abundant elements on earth, but is infrequently encountered in surface waters because of rapid precipitation as

hydroxide or carbonate. Little ingested aluminum is absorbed by humans, and no adverse impacts from human ingestion have been documented (McKee and Wolf, 1963). No criteria have been established for aluminum in drinking water.

Arsenic occurs in trace quantities in surface waters. Elemental arsenic is insoluble in water, but arsenates are highly soluble. Arsenic is bioaccumulated and slowly excreted from the human body. Both acute and chronic ingestion of arsenic can be fatal. A criterion for maximum contamination with arsenic has been established as 0.05 mg/L in drinking water (DHS, 1977).

Cadmium precipitates readily with hydroxide and carbonate at neutral or alkaline pH values. Cadmium ingested from food or water tends to concentrate in the liver, kidneys, pancreas, and thyroid of humans and animals, and is not easily excreted (McKee and Wolf, 1963). A maximum contaminant limit of 0.010 mg/L of cadmium in domestic water has been established (DHS, 1977).

Chromium occurs in several ionic forms, all of which form insoluble hydroxides or carbonates in water at neutral or alkaline pH values. Chromium salts are rapidly excreted from the human body. Trivalent chromium is not considered to be physiologically harmful to humans, but a limit of 170 mg/L has been suggested (USEPA, 1986). Hexavalent chromium has been implicated in intestinal and kidney inflammations. A mandatory contaminant level for all forms of chromium has been established at 0.05 mg/L (DHS, 1977).

Lead is occasionally naturally found in surface waters, but the ion reacts readily with carbonate, hydroxide, and sulfate to form insoluble precipitates. Lead accumulates in bones in humans and is very slowly excreted. Sufficient intake results in lead poisoning. Lead concentrations as low as 0.1 mg/L have resulted in the death of fish. Bacterial decomposition of organic materials is inhibited at lead concentrations of from 0.1 to 0.5 mg/L (McKee and Wolf, 1963). A maximum contaminant level for lead has been set at 0.05 mg/L (DHS, 1977).

Mercury is highly soluble in water as mercuric salts. Mercury is readily absorbed in the gastrointestinal tract of humans and is highly toxic at low concentrations to both humans and aquatic organisms. A maximum contaminant level of 0.002 mg/L of mercury in drinking water has been established (DHS 1977).

Selenium may occur naturally in water as selenite and selenate. Selenium is required in trace amounts in humans and is believed to be toxic at higher concentrations, but proof of human injury is scarce (McKee and Wolf, 1963). Selenium is passed along in the food chain of aquatic systems to lethal levels to fish. A maximum contaminant level for selenium in drinking water has been established at 0.01 mg/L.

Aluminum was present in Morris Reservoir at concentrations ranging from 0.034 to 0.280 mg/L at the surface and 0.178 to 0.695 mg/L at the bottom (Table 2). Aluminum was present in the tributaries at concentrations ranging up to 0.121 mg/L and from the treatment plant at levels ranging from 0.081 to 0.416 mg/L.

Traces of arsenic were found in Morris Reservoir, ranging up to 0.0017 mg/L at the surface and 0.0027 mg/L at the bottom. Arsenic levels in the tributaries ranged up to 0.0008 mg/L and up to 0.0015 mg/L at the treatment plant. The levels of arsenic are well below the established criterion.

Cadmium and lead were not detected from any of the monitoring locations.

Chromium was detected in Morris Reservoir at levels ranging from 0.002 to 0.004 mg/L at the surface and 0.002 to 0.005 mg/L at the bottom. Chromium levels ranged up to 0.003 mg/L in the tributaries and from 0.003 to 0.005 mg/L at the treatment plant. The detected levels of chromium are well below the criterion for protection of domestic water supplies.

Levels of mercury detected in Morris Reservoir were 0.0001 mg/L at the surface and ranged from 0.0000 to 0.0003 mg/L at the bottom. Up to 0.0002 mg/L of mercury were detected in the tributaries, but only 0.0001 mg/L was detected at the treatment plant. Mercury levels are well below the drinking water criterion.

Selenium was only detected from the bottom of Morris Reservoir. The selenium level ranged from 0.0000 to 0.0003, which was well below the criterion for protection of domestic water.

Sediment Characteristics

Sediment samples were collected from near the dam on May 21, 1986, and September 11, 1986, using a Wildco-Ballchek single tube core sampler. Two core samples were collected on each date. Since the upper 2 cm (0.8 inch) sediments are the most active in ion exchange, subsamples from the sediment surface to 1 cm (0.4 inch) and 1 to 2 cm (0.4 to 0.8 inch) in depth were composited from the duplicate samples on each date and submitted to Bryte Chemical Laboratory for analyses. Both leachable and total concentration were determined for nitrate plus nitrite, ammonia plus organic nitrogen, phosphorus, arsenic, copper, iron, and manganese. Leachable analyses were conducted by extraction with distilled water followed by standard analysis procedures (APHA, 1985). Total analyses were conducted using acid digestion followed by standard methods.

Nitrogen. Leachable oxidized nitrogen (nitrate plus nitrite) was found on May 21 at concentrations that were similar at the 0 to 1 cm (0 to 0.4 inch) and 1 to 2 cm (0.4 to 0.8 inch) depths, but on September 11 the concentration was slightly greater at the deeper compared to shallower strata (Table 4). Concentrations of leachable oxidized nitrogen had increased significantly from May 21 to September 11. Concentrations of leachable ammonia plus organic nitrogen were similar between sampling dates and slightly higher in the shallower strata. Total ammonia plus organic nitrogen concentrations declined in both strata from May to September.

Water overlying the sediments was aerobic during May. Ammonia generated during the aerobic decomposition of organic nitrogen is rapidly oxidized to nitrite, which is further oxidized to nitrate. During summer stratification, anoxic conditions develop in the water overlying the sediments due to

Table 4. Results of laboratory analyses (mg/kg) of bottom sediments collected from Morris Reservoir.

	May 21, 1986				September 11, 1986			
	0-1 cm		1-2 cm		0-1 cm		1-2 cm	
	Leachable	Total	Leachable	Total	Leachable	Total	Leachable	Total
Nitrogen								
Nitrate + Nitrite	6.6	-	6.4	-	37	-	47	-
Ammonia + Organic Nitrogen	6.5	2,100	4.4	1,600	5.8	1,600	5.7	1,400
Phosphorus								
Phosphorus	2.3	800	1.4	650	1.7	460	1.6	460
Metals								
Arsenic	0.002	3.8	0.003	1.9	0.002	2.1	0.002	1.9
Copper	0.54	360	0.61	270	0.36	270	0.49	310
Iron	0.12	220,000	0.05	100,000	0.12	96,000	0.10	130,000
Manganese	0.90	1,300	0.88	860	43.7	1,200	47.6	900

depletion of oxygen during decomposition of large quantities of organic materials produced in the epilimnion. Organic nitrogen contained in organic materials settling to the sediments and that already present in the sediments undergo anaerobic decomposition under anoxic conditions to produce ammonia as the end product. However, by September 11 recirculation of the reservoir had begun, producing oxygenated conditions in the water overlying the sediments and conversion of quantities of ammonia to nitrite and subsequently nitrate.

Phosphorus. Both leachable and total phosphorus concentrations were higher in the surface sediment strata than that lying immediately below during May, but were at similar levels during September. Leachable phosphorus decreased slightly in the surface strata from May to September, but increased slightly in the lower strata. Significant reductions in total phosphorus concentrations occurred in both strata from May to September.

Differences from May to September in phosphorus concentrations are related to anoxic conditions during summer stagnation. The mobility of phosphorus in sediments is not directly affected by dissolved oxygen conditions but, rather, the cycling of other chemical species, chiefly iron, to which phosphorus is bound. Chemical reduction brought about by the anoxic conditions during the summer produced dissolution of primarily ferric and manganic compounds, resulting in dissolution and desorbtion of bound phosphorus. Soluble phosphorus contained in the sediments translocates to the overlying water, becoming transported and mixed throughout the water column during reservoir turnover, and resulting in lower phosphorus concentrations in the sediment. Concentrations of phosphorus in the sediments slowly increase as soluble ferrous and manganous ions become oxidized under aerobic conditions to produce ferric and manganic phosphates or other precipitates to which phosphorus becomes adsorbed and organic compounds produced in the epilimnion or carried into the reservoir with winter runoff settle to the bottom.

Metals. Essentially no differences were found in concentrations of leachable arsenic between the upper and lower strata and sampling dates. Total arsenic concentrations decreased slightly in the upper sediment strata from May to September, as a result of solubilization to the water columnm of bound arsenates during summer stagnation (Brannon and Patrick, 1987).

Leachable copper concentrations were slightly higher in the lower strata than the upper strata on both sampling dates and declined in concentration from the earlier to latter date. Total copper concentrations in the upper strata were greater than the lower strata in May, but were less in September. Total copper concentrations decreased in the upper strata and increased in the lower strata from May to September. Slightly acidic conditions during summer stagnation probably allowed some mobilization of copper to either overlying water or deeper sediments.

Little change occurred in leachable iron in either strata from May to September. However, total iron concentrations declined significantly in the surface strata from May to September and increased in the lower strata. During the anoxic conditions of summer stagnation, iron precipitates resolubilize, moving from surface sediments to the overlying water and to deeper sediments. Reservoir turnover in the fall results in mixing of iron throughout the water column and formation of iron precipitates through oxidation of ferrous ions to

ferric compounds. The ferric compounds gradually settle back to the surface sediments.

Leachable manganese concentrations were similar between the surface and lower strata, but increased dramatically from May to September. Total manganese concentrations were higher in the surface than the lower strata. Surface strata concentrations declined slightly, while lower strata concentrations increased slightly from May to September. Solubilization of manganic compounds during summer stagnation allowed translocation of manganese from the upper sediment layer to overlying water as well as deeper sediments. Apparently, manganese movement was not rapid, causing retention of much of the soluble manganese in the upper sediment layer.

Limiting Nutrients

The identification of chemical elements critical to algal growth is necessary to determine methods that will remove or inactivate those elements, and hence restrict algal growth. Bioassays are the only methods capable of determining which elements limit algal growth. The multiple addition bioassay (Maslin and Boles, 1978) was used to determine limiting nutrients in Morris Reservoir. In this bioassay, algae naturally present in the lake and all but one of the nutrients required for algal growth are added to each flask or bottle. Algal growth must then rely on the natural concentration in the water of the nutrient not added. The amount of algal growth in each flask indicates the natural availability of each nutrient. Lack of algal response indicates nutrient limitation.

A triplicate series of 300 ml B.O.D. bottles was used each month from June 1986 through June 1987 to determine limiting nutrients in Morris Reservoir. All glassware and other apparatus were cleaned with a sulfuric acid-sodium dichromate solution prior to the start of each bioassay. Nutrient solutions were prepared with analytical-reagent grade chemicals and deionized distilled water (Table 5). One milliliter of each appropriate nutrient solution was added to each bottle so that each set of three bottles contained all nutrients except one. Control bottles were also used with one set containing all added nutrients and another set containing no added nutrients. Phytoplankton used to inoculate each bottle were collected with a series of net tows. An 80-micron mesh plankton net was emptied through a 153-micron mesh net to exclude zooplankton into a half-gallon plastic bottle after each of six 10-meter (33-foot) tows through the water column. Fifteen milliliters of the phytoplankton inoculum were added to each bottle with a repetitive variable volume dispensing pipette. The bottles were then filled with water from the lake that was filtered through a 1.2 micron pore diameter filter to exclude both zooplankton and algae. The bottles were sealed with glass stoppers and plastic overcaps. Bottles were spaced about 30 cm (12 inches) apart and suspended at a depth of approximately 45 cm (18 inches) from a PVC float near the middle of the reservoir. Bottles were allowed to incubate for a period that varied from 7 days during the more productive summer period to 14 days during the less productive winter period. Bottles were then placed on ice in the dark for transport to the laboratory where they were immediately processed. The sides of the bottles were thoroughly scraped with rubber policemen and the contents strained through 47 mm (1.9 inch) diameter filters, with 1.2 micron pore diameters that were previously washed with 100 ml of distilled water,

Table 5. Stock chemical solutions and principal elements in multiple addition bioassays

	Stock Solution (mg/ml)	Concentrations of Principal Elements (mg/ml)
$CaCl_2$	0.0300	0.0108 Ca;0.0192 Cl
CaO	0.0150	0.0107 Ca
$CoCl_2 \cdot 6H_2O$	0.1200	0.0297 Co;0.0358 Cl
$Co(NO_3)_2 \cdot 6H_2O$	0.1470	0.0298 Co;0.0142 N
$CuCl_2 \cdot 2H_2O$	0.0320	0.0119 Cu;0.0133 Cl
$CuSO_4 \cdot 5H_2O$	0.0470	0.0120 Cu;0.0060 S
$FeCl_3 \cdot 6H_2O$	0.1460	0.0302 Fe;0.0575 Cl
$FeCl_2 \cdot 6H_2O + Na_2EDTA \cdot 2H_2O$	0.1220	0.0290 Fe;0.0368 Cl
$+Na_2EDTA$	0.2040	0.0126 Na;0.1591 EDTA
$Fe(NO_3)_3 \cdot 9H_2O$	0.2180	0.0301 Fe;0.0227 N
$FeSO_4 \cdot 7H_2O$	0.1490	0.0299 Fe;0.0172 S
H_3BO_3	0.0140	0.0024 B
H_2EDTA	0.1500	0.1490 EDTA
KCl	1.9240	1.0090 K;0.9150 Cl
$K_2HPO_4 \cdot 3H_2O$	0.2850	0.9877 K;0.0387 P
KNO_3	2.6820	1.0371 K;0.3716 N
$MgCl_2 \cdot 6H_2O$	0.0900	0.0108 Mg;0.0314 Cl
$Mg(NO_3)_2 \cdot 6H_2O$	0.1130	0.0107 Mg;0.0123 N
$MgSO_4 \cdot 7H_2O$	0.0900	0.0089 Mg;0.0117 S
$MnCl_2 \cdot 4H_2O$	0.0430	0.0119 Mn;0.0154 Cl
MnO_2	0.0240	0.0152 Mn
$MnSO_4 \cdot H_2O$	0.0430	0.0140 Mn;0.0082 S
MoO_3	0.2130	0.1420 Mo
$Na_2B_4O_7 \cdot 10H_2O$	0.0860	0.0104 Na;0.0098 B
$Na_2EDTA \cdot 2H_2O$	0.2040	0.0252 Na;0.1591 EDTA
$Na_2HPO_4 \cdot 7H_2O$	0.4050	0.0695 Na;0.0468 P
$NaNO_3$	2.2500	0.6087 Na;0.3708 N
$Na_2SiO_3 \cdot 9H_2O$	0.6518	0.1054 Na;0.0644 Si
Na_2SO_4	0.0760	0.0246 Na;0.0172 S
$ZnCl_2$	0.2650	0.1271 Zn;0.1379 Cl
$ZnSO_4 \cdot 7H_2O$	0.2650	0.0603 Zn;0.0296 S

dried at 103°C (217°F) for 24 hours, and weighed to the nearest tenth of a milligram. The filter papers were redried at 103°C (217°F) to a constant weight. The differences in weights of the filter papers are due to the dry weight of algae produced during incubation.

Bioassay results (Table 6) show that nutrients which limit the growth of algae in Morris Reservoir vary seasonally both in composition and intensity of limitation. The addition of all nutrients to the bottles during the June 1986 bioassay resulted in increased growth of algae (Appendix 4a). However, algal growth was no greater in the bottles with all nutrients except phosphorus added than in the bottles with no added nutrients, indicating that growth of algae was limited by the availability of phosphorus. The deletion of other nutrients individually from the bioassay bottles resulted in more algal growth than that which occurred in the bottles with no added nutrients, indicating that the natural availability of these other nutrients was sufficient to sustain higher levels of algal growth if sufficient phosphorus were available. The natural concentration of iron was sufficient to allow some increased growth of algae, but became limiting when incorporation into algal biomass depleted reserves, as indicated by the results from the bottles with all nutrients except iron added. Algal growth increased significantly in several bottles in which individual nutrients (including sulfur, copper, and especially zinc) were omitted, indicating inhibition of algal growth by these nutrients. Many nutrients, required in small quantities, become toxic to algae when present at higher concentrations. Algal biomass in the bottles with all nutrients except phosphorus added was less than those with no added nutrients because of inhibition by toxic concentrations of these nutrients.

Sodium was most limiting to algal growth in the July 1986 bioassay (Appendix 4b). However, the nutrient solutions available at that time resulted in the deletion of ethylenediaminetetraacetic acid (EDTA), silicon, and boron in conjunction with sodium. Deletion of EDTA, which is a chelating agent important in maintaining the availability of trace elements to algae, resulted in moderate limitation of algal growth. The limitation of growth exhibited by the deletion of sodium was due to the simultaneous deletion of other important nutrients. Phosphorus was again the nutrient most limiting to algal growth when nutrients were deleted individually. Nitrogen was the next most limiting nutrient, followed by EDTA and iron. Sulfur, copper, and zinc were not added to the bioassay bottles in which individual nutrients were deleted because of previously indicated inhibitory effects, but were added to sets of bottles containing all other nutrients to determine continued inhibition. The addition of sulfur and copper produced no inhibitory effects. The addition of zinc, however, resulted in significantly reduced algal growth. Growth was reduced slightly further with the combined addition of sulfur, copper, and zinc, possibly due to some synergistic effects.

Bioassay results in August 1986 were similar to those from July. Nitrogen, however, was slightly more limiting to algal growth than was phosphorus, while iron did not limit algal growth (Appendix 4c).

Nutrient solutions available beginning with the September bioassay allowed each nutrient to be deleted individually. Phosphorus was the most limiting to algal growth in September, closely followed by nitrogen, and much less closely by iron (Appendix 4d). Zinc was inhibitory to algal growth.

Table 6. Results of multiple addition bioassays from Morris Reservoir (mg of algae)

Test Nut.	6-86	7-86	8-86	9-86	10-86	11-86	12-86	1-87	2-87	3-87	4-87	5-87	6-87
P	1.0	2.1	2.0	1.6	3.4	1.5	1.7	2.5	1.6	1.7	1.7	1.3	0.7
K	1.9	19.6	23.3	9.0	9.6	1.4	1.8	2.5	2.1	2.0	2.4	10.9	1.2
Na	1.4	2.0	4.0	6.1	2.1	1.3	1.4	2.2	1.7	1.9	1.8	6.4	1.5
S	3.4	-	-	-	-	-	-	-	-	-	-	-	-
N	1.9	3.5	1.9	2.2	3.7	1.7	1.5	2.4	1.7	2.2	1.2	3.0	0.8
Si	2.2	15.5	22.0	5.4	3.1	1.3	1.9	2.8	1.9	2.4	3.9	9.3	2.4
Cl	2.1	12.6	24.3	4.8	4.7	0.8	1.4	2.9	2.4	1.8	2.5	9.5	0.9
Mn	2.0	20.8	27.3	6.2	7.5	2.4	2.2	3.1	1.8	2.0	3.4	12.0	1.7
Mo	1.7	22.2	24.7	6.4	6.1	1.5	1.9	2.3	2.1	2.6	3.0	11.6	2.2
Cu	2.7	-	-	-	-	-	-	-	-	-	-	-	-
Co	1.7	20.5	24.3	6.4	5.9	1.8	1.9	2.4	2.2	2.3	3.9	11.2	1.2
Fe	1.2	8.6	23.3	4.2	4.7	1.6	1.4	2.6	2.3	2.1	2.4	9.9	0.8
Edta	1.9	3.6	2.7	5.5	1.9	1.4	2.2	2.6	1.7	2.1	1.9	8.6	1.2
Mg	2.2	21.5	25.4	5.2	6.1	1.6	2.1	2.5	1.9	2.2	3.2	12.0	2.2
B	1.7	22.6	24.1	5.9	5.3	1.3	2.2	2.4	1.7	2.2	3.5	12.0	2.3
Zn	6.2	-	-	-	-	-	-	-	-	-	-	-	-
CuCo	1.7	-	-	-	-	-	-	-	-	-	-	-	-
Ca	1.5	22.3	24.1	5.9	6.0	2.1	2.0	2.7	2.1	2.3	3.7	12.0	2.1
All+	1.2	20.3	24.9	6.4	7.2	2.1	1.7	2.7	2.1	2.4	3.0	12.0	2.0
All-	0.9	1.1	1.3	1.9	1.0	1.1	1.7	2.5	1.8	1.9	2.1	0.9	0.4
All+S	-	20.1	25.3	5.6	8.0	1.3	2.3	2.3	2.0	2.0	3.5	11.7	3.4
All+Cu	-	-	-	6.1	6.2	1.6	2.4	2.4	1.7	2.1	2.9	11.9	2.6
All+Cu+S	-	20.5	25.5	-	-	-	-	-	-	-	-	-	-
All+Zn	-	4.7	5.3	4.8	3.8	1.3	2.0	2.1	2.3	1.8	2.6	7.0	1.9
All+S+Cu+Zn	-	4.0	4.6	3.4	5.5	1.3	2.3	1.9	1.9	1.9	2.2	7.5	1.3

Algal growth was most limited in October 1986 by EDTA and sodium (Appendix 4e). Silicon and phosphorus were other nutrients that were naturally present in short supply relative to the needs of algae. The addition of zinc again was inhibitory to algal growth.

Algal growth was limited more by declining water temperature and light from both decreasing day length and increasing turbidity by November 1986 than any particular nutrient. Differences in growth between bottles with all nutrients added and those with no nutrients added were much less than in previous bioassays (Appendix 4f). Algal growth appeared to be significantly reduced only upon deletion of chlorine.

Essentially no differences in growth existed between bottles with different elements deleted from December 1986 through March 1987 (Appendices 4g through 4j). Algal growth was similar between bottles with all nutrients added and those with no nutrients added. No particular nutrient appeared to limit algal growth.

Increasing temperature and period of daylight and decreasing turbidity by April 1987 stimulated increased production of algae, resulting in nutrient depletion and growth limitation. Nitrogen was the primary nutrient limiting algal growth, followed closely by phosphorus and EDTA (Appendix 4k).

Phosphorus was the most important nutrient limiting algal growth in May 1987 (Appendix 4l). Nitrogen became limiting after growth was stimulated by the addition of phosphorus. The addition of zinc was inhibitory to algal growth.

The bioassay conducted in June 1987 again showed phosphorus to be the most important limiting nutrient (Appendix 4m). Both nitrogen and iron became equally important in limiting continued algal growth following the addition of phosphorus. Chlorine also exhibited growth-limiting effects. The addition of sulfur to bottles containing all nutrients except copper and zinc stimulated significantly higher rates of algal production.

The nutrient in least supply relative to the physiological needs of algae will limit growth. Many elements required in trace quantities by algae occur naturally in high concentrations relative to the needs of algae and do not induce growth limitation. Conversely, some nutrients occur naturally in relatively small quantities, but are required in relatively high concentrations by algae. Morris Reservoir contained concentrations of most nutrients in sufficient quantity to satisfy the physiological requirements of algae. Several nutrients, however, occurred in growth-limiting concentrations at various times of the year. Phosphorus, required in high concentrations in relation to its occurrence, was primarily responsible for limiting algal growth during most of the year. Nitrogen, which is also required in relatively high concentrations by algae, occasionally occurred at levels resulting in limitation of algal growth. Under natural conditions, however, nitrogen would still be available to algae capable of atmospheric nitrogen gas fixation. EDTA and chlorine, both of which through chelation maintain the availability of metals to algae, were each once found to limit algal growth. If additional quantities were made available of the growth-limiting nutrients, additional algal growth would occur until supplies of some other nutrient became exhausted. When not

themselves the primary limiting nutrient, phosphorus and nitrogen were present in quantities sufficiently low to restrict algal growth should additional supplies become available of the primary limiting nutrient. Other nutrients exhibiting secondary importance in limiting algal growth included iron, sodium, and silicon.

Excess quantities of nutrients can produce toxic reactions that limit algal growth. Zinc apparently was present in quantities sufficient to at least meet physiological needs and perhaps suppress algal growth. Additional quantities of zinc often resulted in marked reductions of algal growth. Sulfur and copper also occasionally exhibited suppressive effects.

Biological Characteristics

Phytoplankton

Water samples for identification of algal species were collected approximately bimonthly from Morris Reservoir near the dam with a Van Dorn style sampler at 3 meter (9.8 foot) intervals from the surface to a depth of 12 meters (39.4 feet) or the bottom when depth was less due to summer drawdown. Samples were preserved with Lugol's fixative in 60 ml (1 ounce) glass bottles. Subsamples were transferred in the laboratory to Sedgewick-Rafter Counting Cells for identification and enumeration at 200 power magnification under a microscope.

Phytoplankton populations were dominated by a relatively few species which shifted with time. Green algae (Chlorophyceae) dominated the phytoplankton community in April 1986, but was represented solely by the genus Ankistrodesmus (Appendix 5). A few blue-green algae (Myxophyceae), represented by the genus Anabaena, were present as were diatoms (Bacillariophyceae), and cryptomonads (Cryptophyceae), each also represented by single species.

Aphanizomenon, which was the only blue-green alga present, dominated the phytoplankton community in May 1986. Ankistrodesmus was still the only green alga present. The golden-brown algae (Chrysophyceae) were represented by a single species, while two cryptomonad species were present.

The algal community increased significantly in numbers of individuals in June 1986, producing an algal "bloom". The community was dominated by Aphanizomenon. Chlamydomonas, which was also present in high number, replaced Ankistrodesmus as the dominant green alga. The number of golden-brown algae, represented by Dinobryon, also increased in number. Navicula was the only diatom present, and occurred in relatively low number.

Aphanizomenon continued to dominate the phytoplankton community as the sole blue-green alga in July 1986. Schroederia became the dominant green alga as Ankistrodesmus and Chlamydomonas declined in numbers. A single cryptomonad was present, but at a relatively low population.

Aphanizomenon dominated the phytoplankton community early in August 1986, but was replaced by Schroederia as the dominant species later in the month. Other green algae present included Chlamydomonas and Scenedesmus.

Two diatoms (Cyclotella and Synedra), a golden-brown alga (Dinobryon), and a cryptomonad (Cryptomonas) were present but in relatively low numbers.

The green alga Schroederia and blue-green alga Aphanizomenon were co-dominant during early September 1986. Both decreased significantly in populations by late September and were replaced in community dominance by the green alga Chlamydomonas. Other green algae present included Closteriopsis and Scenedesmus. Diatoms present included Cymbella, Melosira, and Synedra. Cryptomonas was the only cryptomonad present.

Green algae dominated the phytoplankton community in October 1986. Scenedesmus was present in greatest abundance, followed by Golenkinia, Schroederia, Sphaerocystis, and Chlamydomonas. A very large population of the diatom Melosira developed during the early part of the month, but disappeared by the latter part. Other diatoms present included Synedra, Asterionella, Fragilaria, and Stauroneis. The Cryptomonas population increased significantly from the previous month, while the Aphanizomenon population was greatly reduced.

The phytoplankton community was overwhelmingly dominated by a Scenedesmus bloom during November 1986. The other green algal populations (Schroderia and Chlamydomonas) were comparatively unimportant. The small population of Aphanizomenon occurring early in the month was replaced by the other blue-green alga Anabaena later in the month. Other algae present were the diatom Pinnularia, the golden-brown alga Dinobryon, and the cryptomonad Cryptomonas.

The population of Scenedesmus declined in December 1986, but still occurred in bloom proportions. Populations of most species present the previous month increased slightly and several new species appeared. Green algae were represented by Chlamydomonas, Chodetella, Closteriopsis, Golenkinia, Scenedesmus, and Schroederia. Dinobryon was the only cryptomonad. No blue-green algae were present.

The algal community declined significantly in January 1987, with many species disappearing. The green alga Scenedesmus continued to dominate the community, but had declined significantly in population size. Chlamydomonas and Schroederia were the only other green algae present. Diatoms were represented by Asterionella and Synedra. The golden-brown algae and cryptomonads continued to be represented by single species, Dinobryon and Cryptomonas, respectively.

The population of Scenedesmus, though continuing to dominate the community, declined further in February 1987. Chlamydomonas, the only other green alga present, maintained a stable population. Diatoms were present at low population levels and included the genera Asterionella, Cocconeis, and Fragilaria. Dinobryon, a golden-brown alga, was also present at a low population level. The cryptomonad population, represented by the genus Cryptomonas, increased. Blue-green algae continued to be lacking.

The phytoplankton community continued to decline in March 1987. The green alga Scenedesmus had declined to a very low population level. Chlamydomonas, the only other green alga present, was also at a low population

level. Small populations were present of the diatoms Asterionella and Synedra. The population of the cryptomonad Cryptomonas, though small, dominated the community.

Population levels continued to be low in April 1987, but populations of several species increased slightly and several new species appeared. A small population of the blue-green alga Anabaena appeared. Populations of the green algae Chlamydomonas and Scenedesmus remained stable, and Staurastrum appeared. The diatoms were represented by Asterionella and Synedra, and newly appearing Cyclotella and Melosira. The golden-brown alga Dinobryon and crytomonad Cryptomonas maintained stable populations.

Phytoplankton populations increased significantly in May 1987. The golden-brown alga Dinobryon was largely responsible for creation of an algal bloom. The green alga Chlamydomonas also occurred at a high population level. Other green algae included Elakatothrix and Scenedesmus, both of which occurred at low population levels. Blue-green algae were dominated by Anabaena with a small population of Gomphosphaeria. Small populations were present of the diatoms Asterionella, Cyclotella, Gomphonema, and Synedra.

The phytoplankton community declined in June 1987. The green alga Chlamydomonas was the most abundant genus. Other green algae present included Elakatothrix, Scenedesmus, and Staurastrum. Asterionella and Cocconeis were the only diatoms present. The golden-brown alga Dinobryon and cryptomonad Cryptomonas were present at low population levels. A relatively large population of the flagellate Trachelomonas also was present.

Zooplankton

Zooplankton were collected with a vertical tow from near the bottom to the surface of Morris Reservoir near the dam. A Wisconsin-style plankton net was used with 153 micron mesh netting. Collected organisms were transferred to glass bottles containing several drops of rose-bengal dye to stain the zooplankton. Formaldehyde was added after a short period to preserve the organisms. Organisms were identified in the laboratory from a subsample transferred to a Sedgewick-Rafter Counting Cell using the 100 power magnification of a compound microscope.

The zooplankton community in Morris Reservoir was composed of seven species (Table 7). The Cladocera (water fleas) included Bosmina longirostris and Daphnia parvula. Cladoceran eggs and immature forms not identifiable to species were also found. The Cyclopoida (copepods) included the species Cyclops bicuspidatus and Mesocyclops edax and unidentified nauplii. The Podocopa (seed shrimp) were represented by the genus Cypridopsis. Rotifers included the species Kellicottia longispina and Keratella cochlearis. Zooplankton generally exhibited peak concentrations in late spring and again in early fall. The zooplankton community during the spring peak in 1986 was dominated by the copepod Cyclops bicuspidatus. Other zooplankton populations occurred at relatively low levels. The much larger fall peak began in mid-September with the development of a very large population of the water flea Daphnia parvula. The water flea population declined later in the fall, but was succeeded by the development of a large population of Cyclops bicuspidatus, which gradually declined as fall progressed into winter. Other zooplankton populations remained at low levels

Table 7. Zooplankton from Morris Reservoir near the dam (average number per liter)

	4/24/86	5/21/86	6/5/86	6/18/86	7/9/86	7/24/86	8/7/86	8/21/86	9/11/86	9/25/86	10/10/86	10/24/86	11/6/86	11/21/86
Arthropoda														
Cladocera														
Bosmina longirostris	0.0	1.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.5	0.6	0.0	0.6	0.7
Daphnia parvula	0.0	1.0	1.7	9.4	2.1	0.4	0.4	4.6	225.2	80.0	37.1	1.5	0.0	0.7
Eggs	0.0	0.5	1.2	3.1	0.5	0.7	0.4	0.8	43.2	0.5	0.0	0.0	0.0	0.7
Immature	0.0	0.0	0.4	2.7	0.5	0.4	0.0	1.2	89.2	1.6	1.3	0.7	0.0	0.7
Cyclopoida														
Cyclops bicuspidatus	3.1	79.0	83.3	45.3	15.6	6.6	8.8	46.2	5.4	61.9	241.8	161.8	29.4	154.7
Mesocyclops edax	0.7	5.6	2.9	5.8	18.2	12.2	5.5	6.2	8.1	17.5	26.1	6.6	2.4	2.2
Nauplii	0.7	2.0	9.2	15.3	6.2	0.4	1.1	0.8	2.7	0.0	56.0	8.8	3.7	0.0
Podocopa														
Cypridopsis sp.	0.0	0.5	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8	2.2
Rotifera														
Ploima														
Kellicottia longispina	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Keratella cochlearis	0.0	0.5	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	1.5
Total	4.5	89.6	99.1	81.6	44.1	21.1	16.2	59.8	373.8	162.0	362.9	179.4	38.5	163.4

Table 7. Zooplankton from Morris Reservoir near the dam (average number per liter) (continued)

	2/11/86	12/23/86	1/9/87	1/22/87	2/5/87	2/18/87	3/4/87	3/17/87	4/3/87	4/13/87	5/7/87	6/5/87	6/25/87
Arthropoda													
Cladocera													
Bosmina longirostris	3.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Daphnia parvula	5.4	3.0	15.3	2.0	4.4	3.6	32.7	7.8	21.6	2.0	0.4	57.5	33.6
Egg	0.0	0.5	4.9	0.4	0.4	0.4	3.9	1.6	0.4	0.0	0.9	32.9	0.8
Immature	0.6	2.0	11.0	0.4	1.6	2.8	4.9	3.1	1.6	0.0	0.0	27.9	5.0
Cyclopoida													
Cyclops bicuspidatus	41.0	35.8	32.3	15.3	12.0	6.8	6.4	11.5	2.4	4.6	21.1	57.5	10.9
Mesocyclops edax	0.6	1.0	0.5	2.8	3.2	2.0	2.0	3.6	1.2	0.3	0.0	0.0	0.0
Nauplii	0.0	3.5	1.6	0.0	0.0	0.0	1.5	1.6	0.8	1.3	0.9	0.0	1.7
Podocopa													
Cypridopsis sp.	2.4	3.5	0.5	0.0	0.4	0.4	0.0	0.0	0.0	0.3	0.0	0.0	1.7
Rotifera													
Ploima													
Kellicottia longispina	0.0	0.0	0.0	0.0	1.2	0.4	1.5	0.0	0.4	0.7	0.0	0.0	0.0
Keratella cochlearis	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0
Total	53.6	53.3	66.6	20.9	23.2	16.4	52.9	29.2	28.4	9.2	23.3	176.2	53.7

during the fall peak. The population of Daphnia parvula was first to exhibit a significant population increase during the spring of 1987 and was followed by an increase in the population of Cyclops bicuspidatus. Other species continued to occur at low population levels.

Fish

Fish were caught using fishing poles with lures and bait, gill nets, and trot lines. Captured fish were identified, and uninjured fish were returned to the reservoir. Several fish of two different species were retained and submitted to the Department of Fish and Game, Fish and Wildlife Water Pollution Control Laboratory, for analyses of arsenic and copper concentrations. Arsenic levels were analyzed from both flesh and liver, while copper levels were analyzed only from the liver.

Two species of fish, both belonging to the sunfish family (Centrarchidae), were caught from Morris Reservoir. The bluegill (Lepomis macrochirus) was very abundant. The other sunfish was the largemouth bass (Micropterus salmoides), and was quite numerous. Large individuals of both species were common, indicating adequate food supplies. Though not caught, catfish (Ictalurus nebulosus) also occur in Morris Reservoir. Several individuals were transported through the outlet pipes to the water treatment plant during the fall of 1987.

Both arsenic and copper were detected in tissues from bluegill and largemouth bass (Table 8). Arsenic levels were higher in liver than in flesh tissues, but were at normal concentrations in comparison to levels found from these species in other areas of California. Concentrations detected in bluegill were at similar levels in corresponding tissues in largemouth bass. Copper concentrations were much higher in the livers of largemouth bass than in the livers of bluegill. The copper concentrations in the livers of the largemouth bass samples were at elevated levels in comparison to concentrations observed in bass in other areas of the State.

Arsenic levels in the liver and flesh of both bluegill and largemouth bass are well below human health criteria for ingestion in foods. Ingestion of a kilogram (2.2 lbs) of food containing copper concentrations in the range of those found in the livers of the largemouth bass are known to cause gastroenteritis with nausea and intestinal irritation. However, copper is not readily assimilated into fleshy tissues and should not, therefore, be present in edible portions of fish from Morris Reservoir at concentrations that would cause adverse health effects. Copper is also readily excreted by the human body.

Macroinvertebrates

Surficial sediment samples were collected with an Ekman dredge at the monitoring station near the dam for macroinvertebrate analyses. Collected sediments were washed through a number 30 Tyler sieve, and all retained material transferred to jars containing formaldehyde for preservation. In the laboratory, samples were rinsed with tap water and organisms identified using a dissecting microscope.

Table 8. Composite tissue analyses for arsenic and copper in sunfish from Morris Reservoir

Species	Collection Date	Tissue	Concentration (microgram/gram fresh weight) Arsenic	Copper
Bluegill (Lepomis macrochirus)	May 21, 1976	Liver	0.15	6.0
	May 21, 1976	Flesh	0.02	-
Largemouth bass (Micropterus salmoides)	May 21, 1976	Liver	0.10	31
	May 21, 1976	Flesh	0.02	-
	November 6, 1976	Liver	0.10	71
	November 6, 1976	Flesh	<0.02	-

The bottom muds of Morris Reservoir contained very few macroinvertebrates. One chironomid (Stempellinella sp.) and one tubificid annelid (Branchiura sowerbyi) were the only species found. Density was low.

Aquatic Macrophytes

Low elevation aereal photographs were obtained to determine the locations and extent of aquatic macrophytes in Morris Reservoir. Plants were then identified to genus during ground surveys.

Aquatic macrophytes were limited by depth to the periphery of the reservoir, except in the shallower arms (Figure 7). Eight genera were identified. The bullrush Scirpus was the most abundant genus, forming dense stands along large areas of the shoreline. The cattail Typha was nearly as abundant and occupied similar habitat. The rush Elocharis formed dense stands along several areas of the shoreline. Two genera, Polygonum and Potamogeton, formed submersed growths, primarily in the Davis Creek arm of the reservoir. The other genera, which include an unidentified grass (Graminae), arrowhead (Sagittaria), and water plantain (Alisma plantago-aquatica), grew at scattered locations along the periphery of the reservoir.

SYNOPSIS

Sediments in Morris Reservoir have accumulated since the dam was constructed in 1927, causing decreases in the maximum depth by 8.7 feet and storage capacity by 99 acre-feet. The sediment level near the dam is only 1.2 feet below the lower outlet pipes to the Water Treatment Plant. Sediments also serve as both sources and sinks in the biogeochemical cycle of chemical elements important in promoting the water quality characteristics and biological productivity in the reservoir.

Physical, chemical, and biological processes in Morris Reservoir, though interrelated and occurring simultaneously, are highly complex. Development of thermal stratification, which persists from spring through fall, essentially divides the reservoir horizontally into separate systems, each with distinct physical, chemical, and biological processes. The essentially uniformly warm surface layer comprises the epilimnion. The bottom layer, comprising essentially uniformly cold water, is the hypolimnion. The metalimnion, which is also called the thermocline, is the water layer between the epilimnion and hypolimnion in which water temperature changes at least 1°C (1.8°F) with each meter (3.3 feet) of depth. Destratification during the fall creates nearly uniform conditions throughout the water column that persist through the winter.

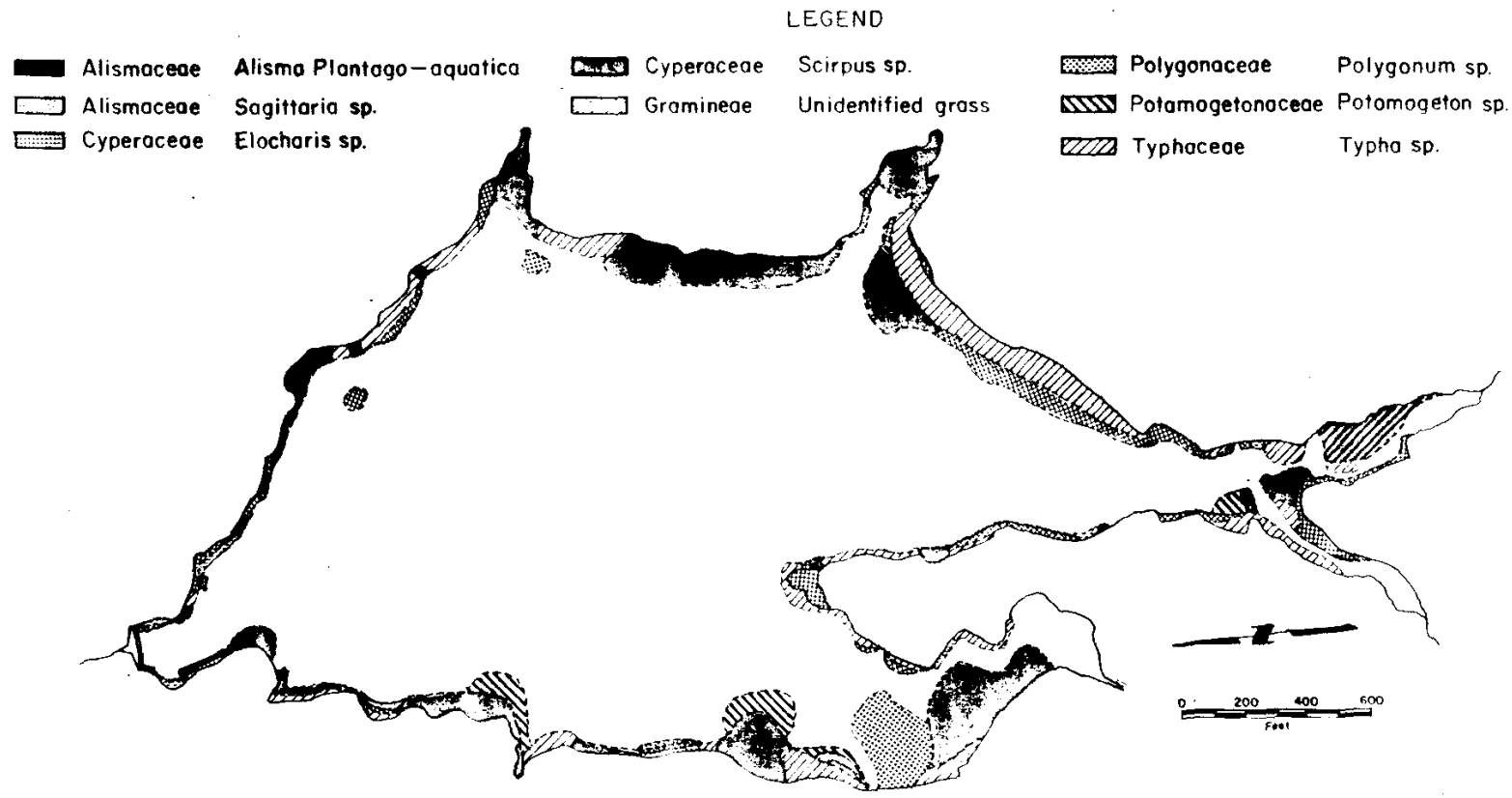

Figure 7. Aquatic macrophytes from Morris Reservoir in the spring of 1986.

Epilimnion

Thermal stratification of Morris Reservoir from warming of the surface water developed by early spring in 1986. Adequate nutrients, increasing photoperiod, and decreasing turbidity stimulated increased production of phytoplankton. Relatively few phytoplankton genera occurred in Morris Reservoir. The green alga Ankistrodesmus dominated the early spring phytoplankton community, but became replaced by mid-spring as water temperatures reached the 64°F to 75°F range optimal for growth of the blue-green alga Aphanizomenon (Gaonker, 1971).

Aphanizomenon continued to dominate the phytoplankton community through early summer, at least in part because of the ability to utilize atmospheric nitrogen when dissolved forms of nitrogen become depleted (Horne and Goldman, 1972; Dunst et al., 1974; Horne, 1975a). Though at a competitive advantage for nitrogen, growth of the blue-green algae community was naturally limited by the unavailability of other required nutrients. Iron is required by blue-green algae for the nitrogen fixation process at higher concentrations than by other groups of algae (Brezonik, 1973), but forms an insoluble ferric hydroxide precipitate, which is largely unavailable to algae, under the aerobic conditions in the epilimnion. Organic chelating compounds, which bind with iron and are assimilable by algae, maintain a limited supply of iron for algal metabolism (Burns and Nriagn, 1976). Phosphorus, which is the least abundant nutrient required by algae, becomes growth limiting when orthophosphate supplies have been incorporated into algal biomass or becomes bound with iron to form a ferric phosphate precipitate or adsorbed to the ferric hydroxide precipitate. Decomposition in the epilimnion of sinking planktonic detritus liberates some nutrients bound in organic compounds, but most decomposition and nutrient liberation occurs in the hypolimnion where nutrients are unavailable to algae (Lauff, 1961; Stauffer, 1986).

In spite of nutrient limitation, blue-green algae dominated the phytoplankton community during the summer. Gas vacuolate buoyancy in blue-green algae allows depth regulation for optimum sunlight and nutrient utilization (Horne, 1975a). Zooplankton, which feed on phytoplankton, are largely unable to graze on blue-green algae. The formation of clumps by blue-green algae prevent ingestion by small species of zooplankton. The zooplankton community in Morris Reservoir is dominated by two species. Large populations of filter-feeding Daphnia occur in Morris Reservoir, but the species is the smaller Daphnia parvula. The large population of zooplanktivorous bluegill fish (Lepomis macrochirus) reduces zooplankton abundance and maintains selective pressure for smaller zooplankton by preferential grazing of larger species. Small herbivores are less effective grazers of algae than are large zooplankton (Pastorok et al., 1981). The other dominant zooplankton species, Cyclops bicuspidatus, is also relatively small, but ingests a wider variety of food, including unicellular algae, other zooplankton, and detritus (Wetzel, 1975), and thus avoids large aggregates of blue-green algae. Secretion of a gelatinous sheath by blue-green algae prevents digestion within zooplankton capable of ingesting larger phytoplankton (Reid, 1961). Other phytoplankton species which at times form large populations, such as Scenedesmus and Cryptomonas, pass through zooplankton essentially unchanged or are poorly utilized (Wetzel, 1975). Zooplankton are also rarely effective in limiting algal populations in general, since expansion of the zooplankton community lags

behind for as long as several weeks the expansion of the phytoplankton community serving as the food supply (Richerson, 1972). Zooplankton may reduce the duration of a phytoplankton bloom, but not the occurrence. Grazing by zooplankton may favor certain populations of phytoplankton through selective utilization of competing species, and also may stimulate increased phytoplankton production through increased nutrient regeneration in the epilimnion.

The addition of copper sulfate to the surface of Morris Reservoir at frequent intervals during the summer of 1986 resulted in cyclical surges in phytoplankton abundance. Copper sulfate inhibits nitrogen fixation by blue-green algae at concentrations as low as 10 ug of copper per liter, and adversely affects most other algae at concentrations ranging from 50 to 100 ug/L (Horne, 1975b). Copper sulfate, however, also has negative effects on other organisms. Adverse effects have been found at copper concentrations ranging from 80 ug/L for the zooplankton Daphnia to 274 ug/L for the bluegill sunfish Lepomis macrochirus and largemouth bass Micropterus salmoides (McKee and Wolf, 1963). Doses of copper sulfate required to control more resistant algae and the high concentrations that form at the reservoir surface upon initial application could adversely affect zooplankton and fish populations in Morris Reservoir. Copper ions are not soluble in water with basic pH values (McKee and Wolf, 1963), and either form precipitates with carbonates and hydroxides in the epilimnion of Morris Reservoir or bind with organic ligands, such as humic and fulvic acids, to form dissolved compounds that are biologically unavailable and not toxic to aquatic organisms (Bruland et al., 1985). Repeated applications of copper sulfate are necessary to maintain dissolved copper ions in the epilimnion.

Aquatic macrophytes were abundant along the periphery of the reservoir and in shallower regions during the summer. Nutrients for plant growth are obtained primarily from the sediments, but are not generally transferred directly to the water from growing shoots (Cooke et al., 1977; Smith and Adams, 1986). Aquatic macrophytes are, however, important sources of nutrients for phytoplankton. Decay of senescent or dehydrated macrophyte shoots release stored nutrients to the water.

Hypolimnion

Organic materials, primarily from phytoplankton production in the epilimnion, settle to the hypolimnion where the bulk of decomposition proceeds. Aerobic conditions following stratification in early spring produce oxidized bacterial decomposition products and maintain oxygenation of surficial sediments. Ammonia produced from aerobic decomposition is oxidized to nitrite and, subsequently, nitrate. Hydrogen sulfide is also produced during bacterial decomposition of organic materials, but is rapidly oxidized in aerobic conditions to sulfate. Precipitated chemical species, primarily iron and manganese, settle to the sediments. Several cations, including those of calcium, carbon, magnesium, phosphorus, potassium, sodium, and sulfur, are transferred from the hypolimnion to the sediments as coprecipitates or adsorbed species with the metallic precipitates (Sholkovitz, 1985). Under aerobic conditions, very little nutrient transfer occurs from the sediments to the overlying water.

Prevention of reservoir circulation by thermal stratification and aerobic decomposition of organic materials contributed to depletion of oxygen in the hypolimnion by mid-spring. Decomposition of additional organic materials proceeded anaerobically. Ammonia, the end product of nitrogenous decomposition, accumulated in the hypolimnion. Some ammonia becomes lost to the sediments through sorption, but ammonia is also gained from the sediments through leaching. Some organic materials become chemosynthetically reduced to produce nitrogen gas. Nitrogen gas not used by nitrogen-fixing bacteria in the sediments rises through the water column, where, if not utilized by nitrogen-fixing blue-green algae in the epilimnion, it is lost to the atmosphere. Hydrogen sulfide is produced as another end proudct in anaerobic decomposition.

Anaerobic reduction of precipitated ferric and manganic hydroxides liberates soluble ferrous (iron) and manganous (manganese) ions (Mortimer, 1971). Phosphorus and other coprecipitated cations, which do not directly enter oxidation-reduction reactions, are incidentally released and become distributed in the overlying water. Soluble iron and manganese in the sediments diffuse into the water column or deeper into the sediments (Stauffer, 1986). Ferrous ions and hydrogen sulfide immediately combine to form the exceedingly insoluble ferrous sulfide precipitate (Schindler, 1985). Hydrogen sulfide accumulates only after most of the ferrous ions have been precipitated (Keeney, 1972; Stauffer, 1986). Other metals, including copper, subsequently precipitate as sulfides.

Anoxic conditions in the hypolimnion create unsuitable habitat for most aquatic organisms. Fish are unable to survive under such conditions, thus limiting the fish fauna to species tolerant of warm temperatures in the epilimnion. Bottom-dwelling macroinvertebrates are limited to facultative anaerobes. Burrowing by macroinvertebrates influences the exchange of nutrients from sediments to the overlying water. Chironomids, such as Stempellinella from Morris Reservoir, may increase the rate of release of nutrients from sediments through respiratory movements in burrows that increase contact of interstitial water with nutrient-rich sediments. Tubificids, such as Branchiura sowerbyi from Morris Reservoir, however, may increase deposition of nutrients through mineralization from digestion of sediment particles (Gallepp, 1979; Graneli, 1979). Oxidation-reduction reactions, though, are of far greater significance in controlling nutrient release and deposition in the sediments.

Holomixis

Decreasing air temperatures during the fall cause surface water temperatures to cool. The cooler water sinks to lower strata of equal temperature-dependent density. The process continues until the entire reservoir has reached isothermal conditions. Winds cause the entire water column to mix (holomixis), distributing oxygen and nutrients throughout. Aerobic conditions throughout the reservoir cause oxidation of chemical species. Hydrogen sulfide and ammonia are oxidized to sulfate and nitrate, respectively. Iron and manganese are oxidized to hydroxides. Iron, primarily, also combines with phosphorus to form ferric phosphate precipitates. Settling ferric and manganic hydroxide precipitates scavenge phosphate and other nutrients and metals from the water column through adsorption (Sholkovitz, 1985; Sigg, 1985).

Abundant nutrients remaining in the euphotic zone contribute to abundant phytoplankton growth following lake turnover. Decreasing temperatures and photoperiod, and increasing turbidity from suspended materials carried into the reservoir with storm runoff gradually restrict phytoplankton growth through the winter. Certain blue-green algae, including Aphanizomenon and Anabaena found in Morris Reservoir, form akinetes (resting cells) that overwinter in the bottom sediments (Phinney, 1960).

As temperatures warm during the spring, thermal stratification develops, and the cycle is repeated.

EVALUATION OF TASTE AND ODOR PROBLEM

Morris Reservoir is rich in nutrients that support abundant phytoplankton growth. Thirteen of the 28 genera of algae present are known to cause tastes and odors in water supply reservoirs from algal excretory products or cell decay (Table 9). Several algal genera known to cause tastes and odors dominate the phytoplankton community in Morris Reservoir, including Aphanizomenon, Chlamydomonas, Dinobryon, Melosira, and Scenedesmus. The blue-green alga Anabaena produces foul tastes and odors even when present at small population levels (Palmer, 1977).

Thermal stratification in Morris Reservoir occurs in early spring and continues through early fall. Decomposition of organic materials depletes the hypolimnion of oxygen by mid-spring. Chemical reduction of inorganic compounds under anaerobic conditions results in the dissolution of iron and manganese precipitates, and mobilization into hypolimnetic water of iron and manganese, and coprecipitated calcium, carbon, magnesium, phosphorus, potassium, sodium, and sulfur. Iron, manganese, potassium, and sodium are metallic species producing tastes in water. Iron concentrations were sufficiently high to produce detectable tastes during July and August and from December through March. Manganese concentrations were sufficient to produce detectable tastes from June through November.

Organic materials decomposing anaerobically in the hypolimnion during thermal stratification result in production of hydrogen sulfide from reduction of sulfates. Hydrogen sulfide is characterized by a rotten egg odor. Odor from hydrogen sulfide was detectable in water collected from the hypolimnion from July through August.

Copper sulfate was regularly used from spring through fall to control phytoplankton growth in the epilimnion of Morris Reservoir. Aerobic conditions result in precipitation of copper and coprecipitation of sulfate to the hypolimnion where anerobic reduction converts the sulfate to hydrogen sulfide. Iron, which under aerobic conditions following fall turnover precipitates much of the phosphate liberated under anaerobic conditons in the hypolimnion, forms an insoluble ferrous sulfide precipitate in the presence of hydrogen sulfide in the anaerobic hypolimnion. Following fall turnover, more phosphorus is available for algal growth in the epilimnion from lack of precipitation with iron. The addition of copper sulfate to control algal growth results in increased availability of phosphorus, which is the nutrient required by algae that is least present relative to physiological requirements and increased availability stimulates increased production of algae.

Table 9. Algae from Morris Reservoir known to cause tastes and odors in water supplies.

Genera	Tastes and Odors Produced
Myxophyceae (Blue-green algae)	
Anabaena	Grassy, musty, septic
Aphanizomenon	Grassy, musty, septic
Gomphosphaeria	Grassy
Chlorophyceae (Green algae)	
Chlamydomonas	Musty, grassy, fishy, septic
Scenedesmus	Grassy
Staurastrum	Grassy
Bacillariophyceae (Diatoms)	
Asterionella	Fishy
Cyclotella	Fishy
Fragilaria	Musty
Melosira	Musty
Synedra	Grassy, musty
Chrysophyceae (Golden-brown algae)	
Dinobryon	Fishy
Cryptophyceae (Cryptomonads)	
Cryptomonas	Fishy

MANAGEMENT ALTERNATIVES FOR RESERVOIR RESTORATION

Excessive phytoplankton production results in unpalatable tastes and odors in water for domestic use from Morris Reservoir. Phytoplankton are directly responsible for the production of certain tastes and odors and indirectly responsible when decomposition produces anoxia in the hypolimnion, allowing production of tastes and odors associated with decomposing organic materials, hydrogen sulfide, and metallic elements. Control of phytoplankton growth is the key to controlling tastes and odors in domestic water from Morris Reservoir.

Phytoplankton growth is dependent on water temperature, light, and nutrients. Cold water temperatures naturally restrict phytoplankton growth during the winter, while growths of different phytoplankton species are favored by the gradual rise and fall of water temperatures from spring through fall. Control of water temperatures to restrict or favor growths of certain algal species is impractical.

Light penetration into the reservoir is reduced from increased turbidity during the winter, which also naturally restricts phytoplankton growth. Decreased turbidity allows increased light penetration from spring through fall, which stimulates increased phytoplankton production. Light reduction to restrict algal growth can be achieved during the algal growing season by artificially increasing turbidity or covering the reservoir surface. Colloidal materials that remain suspended and dyes that inhibit light transmission are materials capable of reducing light required for algal photosynthesis. Such materials are inappropriate for use in raw water supplies such as Morris Reservoir, however, since removal may not be practical from finished drinking water. Reservoir surface covers include plastic films, floating objects, and aquatic plants. The large expanse of Morris Reservoir renders surface films impractical. Floating objects would be blown by winds into piles on shore or lost during reservoir spillage. Aquatic plants endemic to Morris Reservoir are incapable of forming a surface cover. Other aquatic plants native to Northern California, such as the water lily (Nuphar polysepalum), may form dense surface mats, but have floating leaves that only extend on petioles about 12 feet from subterranean rhizomes (Prescott, 1969). The water hyacinth (Eichornia crassipes), naturalized from tropical America to Central California, forms dense mats with floating roots. Ideally suited for providing dense covers in quiet waters, the water hyacinth has become a severe nuisance by choking waterways to prevent navigation. Significant environmental damage would occur downstream if the water hyacinth escaped from introduction to Morris Reservoir.

An adequate nutrient supply is required for algal growth. Certain nutrients are abundant but required by algae in only trace quantities, while other nutrients are relatively scarce but have a high requirement by algae. The nutrient present in least supply relative to the physiological requirements of algae will restrict algal growth. Several nutrients were identified that limited algal growth in bioassays. The most important limiting nutrient in Morris Reservoir was phosphorus. Further restriction of phosphorus availability would reduce algal growth and improve the water quality in Morris Reservoir.

Several techniques are available for reducing the supply of phosphorus in reservoirs. Other restoration techniques are also available to reduce nutrient loads or decrease algal standing crops.

Harvesting

Mechanical harvesting of phytoplankton and aquatic macrophytes removes nutrients contained as organic matter. A mechanical surface skimmer was developed for harvesting nuisance algal growths in Clear Lake (Koopman and Oswald, 1977). However, the harvester was only effective in removing surface scums, and is therefore most appropriate for aesthetic enhancement of small bays rather than whole lake treatment to remove phytoplankton. Mechanical harvesting of submerged aquatic macrophytes in Canadian lakes resulted in significant reductions in phytoplankton biomass (Wile, 1978). Chemical analyses of plants indicated that significant removal of nutrients occurred from mechanical harvesting (Muztar et al., 1978). Mechanical harvesting of macrophytes in Morris Reservoir would probably not produce significant benefits. Lack of dense growths of submerged aquatic macrophytes would make harvesting inefficient in removing either plant biomass or organically bound nutrients. Harvesting of dense stands of emergent macrophytes along the reservoir periphery would probably remove significant quantities of nutrients from a mainly terrestrial origin. Decreased shoot acretion to the reservoir from harvesting would probably have minor beneficial effects on nutrient loading in relation to the large quantity of nutrients regenerated from the bottom muds. Nutrient removal from mechanical harvesting would not likely reduce phytoplankton growth.

Hypolimnetic Withdrawal

Release of hypolimnetic water during summer stratification exports oxygen-poor and nutrient-rich water. Exported hypolimnetic water must be replaced by diverting inflowing water to maintain sufficient volume of water for aerobic decomposition in the hypolimnion. The effectiveness of hypolimnetic withdrawal during summer stratification has received little documentation. Hypolimnetic water was siphoned with an Olszweski tube from Lake Piburger in Austria, but produced no discernable change in water quality after 10 years of operation (Rott, 1983).

Hypolimnetic withdrawal from Morris Reservoir during summer stratification would not be effective with current water delivery procedures. Inflowing water is not sufficient to prevent anoxia and depletion of the hypolimnion. Phosphorus and metals releases and generation of odors associated with decomposition would continue to occur. Poor quality water from the hypolimnion would increase treatment costs and produce consumer complaints. Release of hypolimnetic withdrawals to Davis Creek with epilimnetic releases to the treatment plant would exacerbate water supply problems.

Modification of the delivery system to the treatment plant to allow extraction of water supplies from Davis Creek would enhance benefits from hypolimnetic withdrawal. Release of hypolimnetic water to Davis Creek from Morris Reservoir during summer stratification would allow aeration, volatilization of odiferous gases, and oxidation and precipitation of metallic species.

Epilimnetic withdrawal from Morris Reservoir during winter months would reduce treatment cost by providing less turbid water, while hypolimnetic releases of quantities of water that would otherwise spill over the dam crest would export nutrients and sediments.

Dilution and Flushing

Dilution of lake water with water low in nutrients reduces the concentrations of nutrients available for algal growth. Flushing increases the rate of plankton loss and may also reduce nutrient concentrations when nutrient levels in the water source are less than those in the lake. An upstream impoundment was found to develop blooms of algae during summer stagnation, but not the downstream reservoir (Fiala and Vasata, 1982). Dilution water from the upstream reservoir was low in nutrients from biological uptake and precipitation or sorption of phosphorus with iron. Dilution of toxins from blue-green algae inhibitory to other algae allows development of less noxious competing species (Welch, 1981). Lake flushing during winter with water low in phosphorus reduced reservoir phosphorus levels and growth of blue-greeen algae (Hosper, 1985). Control of watershed development played a significant role in providing dilution and flushing water low in phosphorus.

Development of additional storage facilities in the Davis Creek drainage would allow dilution or flushing of Morris Reservoir. Multiple outlets should be planned in any storage facility for quality control of releases. The watershed should be carefully managed, since disturbance, especially through poor logging practices, significantly increases nutrient loading and sediment transport (Brezonik, 1973; Smith, 1976).

Dredging

Dredging of sediments has been employed in lakes to remove nutrients and toxicants and to provide deeper water for boat travel and recreation. Sediments have been removed by lake drawdown and excavation, grab buckets, and hydraulic dredges. Dredging sediments in Lake Trehorningen in Sweden reduced phosphorus concentrations, but failed to decrease algal biomass (Ryding, 1982). High nutrient loading from tributary streams provided sufficient phosphorus to maintain algal productivity. Problems associated with sediment dredging include resuspension of sediments, liberation of nutrients, oxygen depletion from decomposition of released organic materials, liberation of toxic substances, and disposal of sediments (Peterson, 1982). Costs for sediment removal are dependent on the type of equipment, size of the project, availability of a disposal area, and density of the sediments. Costs for sediment-dredging projects have ranged from $0.18 to $10.70 per cubic yard of material (Cooke et al., 1986).

Morris Reservoir has accumulated approximately 99 acre-feet of sediments. Distributions of the sediments over the original reservoir bottom and of nutrients within the sediments are largely unknown. The sediments contain high concentrations of at least phosphorus, copper, iron, and manganese, which would be resuspended during dredging and may require special disposal handling. These materials are highly mobile within anoxic sediments and are probably distributed throughout the sediment deposits. Assuming complete sediment

removal, costs would range from $29,300 to $1,710,000, based on previous projects (Cooke et al., 1986). Sediments and nutrients would continue to accumulate in Morris Reservoir following dredging. Recent significant watershed disturbance (logging) will exacerbate the rate of sediment and nutrient accumulations.

Aeration - Circulation

Artificial circulation of lakes by bottom aeration prevents thermal stratification and maintains aerobic conditions throughout the water column. Aerobic conditions at the sediment-water interface prevent regeneration of nutrients and metals from chemical reduction (Lorenzen, 1977). Aerobic decomposition of organic materials produces oxidized byproducts, which allows formation of sulfates rather than hydrogen sulfide. Aeration also mixes phytoplankton from the euphotic zone, which reduces the competitive advantage of buoyant depth regulation by blue-green algae and favors small green algae (Pastorok et al., 1981). Light required for photosynthesis by algae and submerged macrophytes may be reduced from circulation of flocculant sediments. Carbon dioxide produced during aerobic decomposition may increase in the surface strata during aeration, which will decrease the pH, favor cyanophagic activity, and shift phytoplankton community dominance from blue-green algae to green algae. Habitat for fish and zooplankton will increase to encompass the entire water column. Zooplankton may increase in abundance with larger species replacing smaller species, due to increased food supply from circulation of detritus and the shift from blue-green to green algal species, vertical habitat expansion, and decreased pressure from sight-dependent predation in the more turbid water. Reduction of algal abundance results from decreased nutrient supply, decreased photosynthesis, mixing of algae in the water column, and increased grazing by zooplankton.

Adverse impacts from circulation by aeration may result from improper design and application (Pastorok et al., 1981). Incomplete mixing from an undersized aeration system may increase organic detritus and suspended sediment in the epilimnion, which would reduce water clarity. Nutrients available to algae may increase from epilimnetic decomposition of detritus and recirculation of nutrients from the hypolimnion. Settling of algae from the epilimnion may be reduced, but algal distribution in the water column may be increased. Effectiveness of zooplankton grazing may be reduced from increased turbidity and distribution of algae in the water column. Increased algal abundance in the epilimnion would decrease carbon dioxide, resulting in a higher pH, reduced cyanophagic activity, and a shift from green to blue-green algae, which would further decrease the effectiveness of zooplankton grazing.

Properly designed systems may also produce adverse impacts. Circulation by aeration produces nearly uniform temperatures from the surface to the bottom of the water column, which would be just slightly lower than the surface temperature under stratified conditions. Cold water required for certain fish, especially salmonids, becomes eliminated. Warmer temperatures may stimulate increased bacteria-mediated phosphorus release from the sediments (Welch et al., 1986). In lakes where algal growth is limited by nutrient availability, induced circulation may increase nutrients and algal growth.

Statistical analyses of data from 41 lakes that had been artificially circulated by aeration showed that the most important design criteria was aeration intensity (Pastorok and Grieb, 1984). Lakes exhibiting good mixing from aeration generally used more than 20 standard cubic feet per minute (SCFM) of air per million square feet of surface area (Lorenzen and Fast, 1977). Theoretical results indicate that approximately 30 SCFM of air per million square feet of surface area would be required to achieve good mixing.

Aeration systems provide fairly efficient mixing of lake water and are easy to install and operate. A compressor on shore delivers air to plastic pipe containing a series of holes held just above the lake bottom. Rising air bubbles result in oxygen diffusion and upwelling of water.

Morris Reservoir, with a surface area of 1.52×10^6 square feet, would require approximately 45 SCFM of air to be injected at the bottom to maintain adequate mixing. Since the reservoir is relatively shallow (45 feet deep), a 9 horsepower single-stage reciprocating air compressor with a working pressure of less than 50 pounds per square inch (psi) should be satisfactory (Lorenzen and Fast, 1977). A variety of materials can be used for the air distribution system, including steel, polyethylene, and polyvinylchloride (PVC). The distribution manifold should be suspended 3 to 6 feet above the bottom to minimize sediment entrainment. Published information on costs of aeration systems is scarce. An aeration system producing 1,200 CSFM cost $113,000 (1983), which represented $123 per surface acre (Cooke et al., 1986). An aeration system for Morris Reservoir would cost $4,300 based on these figures.

Mechanical Mixing

Lake circulation has also been achieved using mechanical devices. In an offstream storage reservoir, river water was pumped through a series of jets set at an upward angle at the bottom to facilitate mixing (Lorenzen and Fast, 1977). Destratification of a 30 acre-foot lake in Ohio was achieved by pumping water from the bottom to the surface at a rate of 6.4 cubic feet per second. Conversely, a 1,000 acre-foot lake in Oklahoma was destratified using a 42 inch diameter fan blade and 0.5 horsepower electric motor to pump water from the surface to the bottom.

Mechanical mixing has not been sufficiently utilized in lake destratification to determine design criteria. Other benefits, such as maintenance of an oxidized microzone at the sediment-water interface, have not been determined.

Mechanical destratification had been attempted in Morris Reservoir. A hypolimnetic pump delivered less than 1 cubic foot per minute of water from a depth of approximately 7 meters (23 feet) to the surface. Both the rate and depth of pumping were inadequate to destratify the reservoir, but probably enhanced algal growth by distributing nutrient-rich water to the surface. Mechanical systems for destratification are not advised for Morris Reservoir, due to the lack of information on design and benefits.

Hypolimnetic Aeration

Hypolimnetic aeration increases the dissolved oxygen content of the hypolimnion without destratification of the water column. Oxygenation of the hypolimnion maintains the oxidized microzone at the sediment-water interface to prevent solubilization of metals and nutrients, and produces oxidized products of decomposition which reduces ammonia and hydrogen sulfide formation (Verner, 1984). Mixing of the epilimnion and hypolimnion does not occur, though the hypolimnion temperature may increase.

Hypolimnetic aeration can be achieved through mechanical agitation, oxygen injection, or air lift. Mechanical agitation relies on pumping water from the hypolimnion to the treatment facility, such as a splash basin located on shore, and gravity return to the hypolimnion. Some warming of the water occurs, and previous results indicate poor gas exchange efficiency (Cooke et al., 1986). Injection of pure oxygen into the hypolimnion has proven effective, but may result in mixing of the hypolimnion and epilimnion. Air lift systems may rely on either full lift, which lift water to the surface and then back to the hypolimnion, or partial lift, which aerate the hypolimnetic water without transport to the surface.

Hypolimnetic aeration systems must be of adequate capacity to produce the desired results. Use of larger capacity systems is desirable to compensate for unforeseen variations in oxygen consumption rates, hypolimnentic volume increases due to warming, and temporary equipment shutdown. Nitrogen gas may become supersaturated from air injection, which could be toxic to fish.

Commercially available air lift hypolimnetic aeration systems are relatively expensive. The LIMNO system, marketed by Aqua Technique Incorporated (formerly marketed by Atlas Copco Aquatec), has been effectively used for water quality restoration in many lakes. A LIMNO system designed for Morris Reservoir would cost $54,460, plus approximately $10,000 for installation (Appendix 6). The LIMNO system requires the unit to be completely submerged at all times. The system quoted by Aqua Technique Incorporated has a height of 33 feet. Drawdown of Morris Reservoir during the summer would expose the unit and prevent operation. Height of the LIMNO system can be reduced to a minimum of 25 feet. Summer drawdown would still expose the unit. A 25 foot high LIMNO system with a diffused air option would enable hypolimnetic aeration during early summer and aeration-circulation during later summer. The cost for the LIMNO/diffused air system would be the same as that of the 33 foot LIMNO system (R. Geney, Aqua Technique Incorporated, pers. comm.). The LIMNO/diffused air system is no more advantageous than aeration-circulation, but costs significantly more.

Full lift and other partial lift hypolimnetic aeration systems also require inundation for operation. Some systems may be designed with telescoping parts, but these would be more expensive to build and operate less efficiently. Less oxygen is exchanged as the lift height is reduced. In lakes undergoing severe summer drawdown, such as Morris Reservoir, no air lift hypolimnetic aeration system may be appropriate (Lorenzen and Fast, 1977).

Hypolimnetic aeration employing mechanical agitation (Figure 8) is better suited to lakes experiencing severe drawdown. Though previous systems

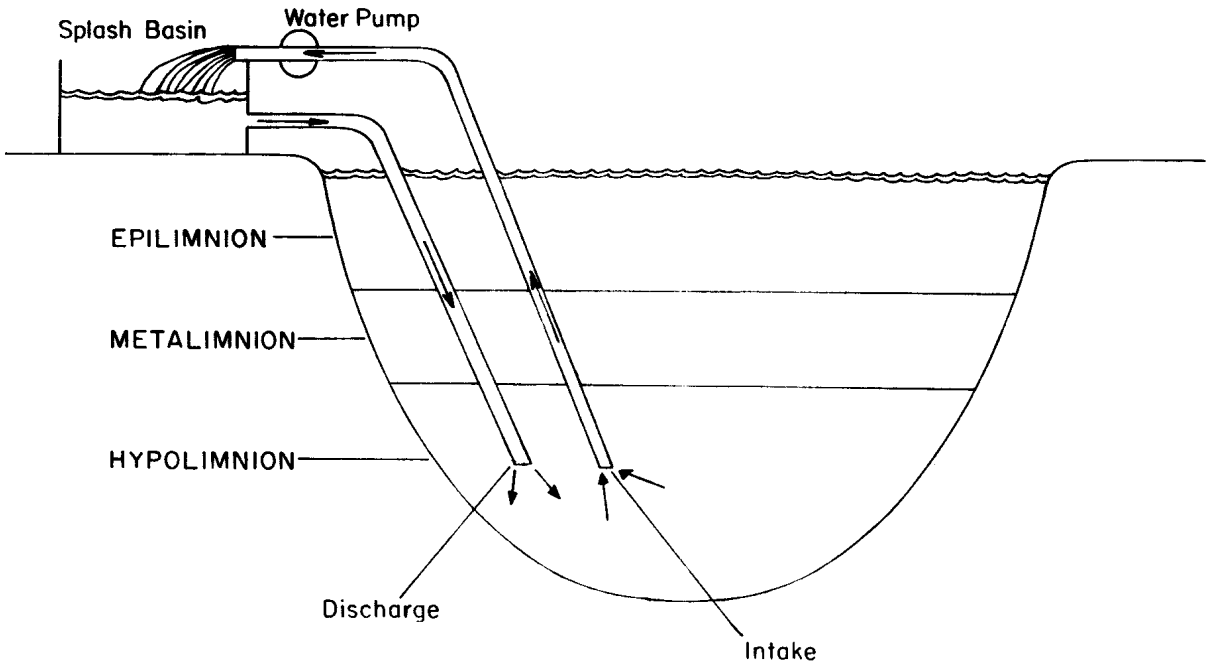

Figure 8. Mechanical aeration system used for hypolimnion aeration. (Modified from Lorenzen and Fast, 1977.)

apparently experienced relatively poor gas exchange, more sophisticated splash basin design may significantly increase oxygen transfer efficiency. Costs for mechanical agitation systems would probably be slightly greater than aeration-circulation systems due to increased energy required to pump water rather than air, but would have the advantages of not inducing destratification or mixing nutrients into the euphotic zone.

Nutrient Inactivation

Nutrient inactivation limits phytoplankton growth by reducing the availability of an essential nutrient. Reductions of phosphorus levels have been the goal of nutrient-inactivation attempts, since phosphorus has been identified as critical in limiting algal growth in most lakes (Smith and Shapiro, 1981). Materials investigated for phosphorus-reduction applications in lakes include fly ash, clays, and various metallic compounds. Fly ash contains water-soluble impurities that may be toxic to aquatic life, while clays have poor phosphorus-binding capabilities (Theis and DePinto, 1976). Compounds of aluminum, calcium, iron, lanthanum, and zirconium are effective in inactivating phosphorus. Lanthanum is toxic to aquatic life at relatively low levels, while both lanthanum and zirconium are prohibitively expensive (Peterson et al., 1974, 1976). Calcium compounds are ineffective in removing phosphorus at pH levels less than 9. Iron compounds are undesirable since ferrous phosphate precipitates become solubilized under anoxic conditions. Aluminum compounds form insoluble precipitates with phosphorus, are relatively inexpensive, and are apparently not toxic to aquatic organisms at the pH and dosage required for phosphorus removal (Cooke et al., 1986).

The dissociation products of aluminum sulfate, which is predominantly used for nutrient inactivation applications, are pH dependent, which is itself affected by the dosage. Insoluble aluminum hydroxide, to which certain phosphorus fractions become tightly bound, and aluminum phosphate form at pH 6 to 8, while soluble species form at pH values greater than 8 (aluminate) or less than 6 (aluminum ion). The insoluble aluminum precipitates scavenge phosphorus from the water column while settling to the sediment surface to form a floc that prevents phosphorus regeneration. Soluble aluminum species are not effective for phosphorus inactivation and may be toxic to aquatic life (Cooke et al., 1986). Sodium aluminate has been added in conjunction with aluminum sulfate to maintain pH levels favorable for formation of insoluble aluminum hydroxide (Kennedy and Cooke, 1980). An alternate and preferred method maximizes dosage based on neutralizing capability of the carbonate alkalinity of a lake (Kennedy and Cooke, 1982).

Aluminum sulfate additions to lakes have produced significant improvements in water quality by lowering phosphorus concentrations, and subsequently decreasing phytoplankton production or shifting dominance from blue-green species to green species, and increasing hypolimnetic dissolved oxygen levels (Soltero et al., 1981; Cooke et al., 1982; Welch et al., 1982; Garrison and Knauer, 1983). Phosphorus regeneration from the sediments has been effectively controlled by the aluminum hydroxide floc for as long as 12 years (Welch et al., 1986). However, phosphorus levels and phytoplankton production have gradually increased from continued nutrient input and sedimentation that covers the floc to reduce effectiveness in phosphorus adsorption (Garrison and Knauer, 1984; Welch et al., 1986).

An alternate method of nutrient inactivation does not rely on the formation of a floc at the sediment-water interface to control phosphorus regeneration, but rather nutrient removal from the water column. Blocks of ferric alum suspended in cloth bags at the surface of a lake slowly dissolve to maintain a steady release of iron to the euphotic zone, which results in formation of precipitates containing phosphorus (May 1980). Algal growth has been reduced by such treatments in ponds. Nutrient regeneration from bottom sediments, however, must be controlled with other methods.

Treatment costs using aluminum sulfate have been moderate, with a large part of the expense related to equipment procurement and modification. Earlier treatments used barges for dispersal of aluminum sulfate and cost about $900 per treated acre. More recent applications have used modified weed harvesters, with cost per treated acre averaging $670 (Connor and Smith, 1986). Total cost to treat Morris Reservoir, based on these figures, would amount to $23,500 to $31,500 for a treatment that may last an indefinite number of years.

Nutrient inactivation with aluminum sulfate is a relatively recent development. Little data are available to document long-term effects. Several potential effects, however, may be detrimental. A decrease in pH below 6, which would likely occur at the surface of a lake from the addition of concentrated aluminum sulfate or throughout the water column from miscalculation of maximum safe dosage, would result in formation of soluble aluminum ions. Toxicity of aluminum ions to aquatic life has not been well defined, but at least some fish species have succumbed to levels as low as 70 ug/L (McKee and Wolf, 1963), which could be expected from an aluminum sulfate dose that caused a decline in pH to less than 6. Effects such as chronic toxicity and bioaccumulation in aquatic organisms also have not been investigated.

Drinking water standards for aluminum have not been promulgated by the U. S. Environmental Protection Agency. The Illinois Pollution Control Board, however, has proposed a limit for aluminum in drinking water of 100 ug/L because several studies have linked aluminum consumption with Alzheimer's disease and kidney dialysis patients treated with water containing aluminum have developed dialysis dementia (Anonymous, 1986). Aluminum sulfate has also been found to increase the lead content of water where lead service pipes are used (McKee and Wolf, 1963). Lead is a cumulative toxin to humans.

Treatment of lakes with aluminum sulfate is highly effective for removal of inorganic and particulate phosphorus, but not dissolved organic phosphorus. Some blue-green algae synthesize alkaline phosphatase at low inorganic phosphorus levels that enable utilization of phosphorus from dissolved organic molecules, which may provide sufficient phosphorus to maintain a blue-green algal bloom (Francko and Heath, 1981).

Floc formation following aluminum sulfate treatment effectively traps and concentrates bacteria. Bacteria have been found to survive in floc at the bottom sediments for a considerable period of time. A potential health hazard exists if water treatment facilities are unable to destroy pathogenic bacteria which are concentrated and may be protected by the floc (Bulson et al., 1984).

Floc layers over firm sediments have been redistributed to the center of shallow lakes from wind-induced mixing (Welch et al., 1986), which then

allows solubilization of phosphorus from the exposed sediments. Drawdown of Morris Reservoir, which has resulted in sediment consolidation, would probably cause redistribution of floc to the deepest portion of the reservoir.

Sulfate levels can be significantly elevated following lake treatment with aluminum sulfate. Anoxic conditions that may develop in the hypolimnion would allow increased production of hydrogen sulfide with eventual reconversion to eutrophy from uncoupling of the iron-phosphorus sink.

Biological Control

Biological control of nuisance populations of algae utilizes natural control agents, such as pathogens and grazers, or manipulation of the environment to favor more desirable species. Advantages of biological control methods include low cost, ease of application, and continued pressure against selected organisms without additional treatment.

Pathogens infectious to algae include fungi, bacteria, and viruses (Schuytema, 1977). Laboratory studies have demonstrated effectiveness of these pathogens against specific species of nuisance blue-green algae, which in Morris Reservoir include Anabaena, Aphanizomenon, and Gomphosphaeria. Field studies in natural bodies of water to determine host specificity and nuisance control capabilities of pathogens have not been conducted.

Zooplankton populations can affect algal abundance and community composition through selective grazing (Porter, 1981). The size of zooplankton affects the size of algae ingested. However, even large-bodied zooplankton are unable to ingest large clumps of certain blue-green algae, including Anabaena and Aphanizomenon, and actively reject such filaments (Hartmann, 1983; Cooke et al., 1986). Smaller clumps and single filaments are ingested. Grazing by zooplankton would be expected to affect populations of green algae, diatoms, and other single-celled algal groups, but not filamentous blue-green algae nor certain other noxious species, such as Scenedesmus and Cryptomonas, that are not digestable. Zooplankton may also affect the phytoplankton community through nutrient cycling. Nocturnal movement of zooplankton to the surface to feed are followed by diurnal transport of organic materials to deeper water where digestion results in excretion of nutrients. However, an anoxic hypolimnion restricts zooplankton habitat and results in nutrient recycling within the epilimnion. Selective pressure on other algal groups and nutrient recycling within the epilimnion by zooplankton may provide competitive advantages for blue-green and other noxious species of algae.

Fish are primarily responsible for controlling size of zooplankton through selective pressure against larger species. Certain fish also feed directly or coincidentally on phytoplankton. The threadfin shad (Dorosoma petenense) has been widely introduced throughout California as forage for game species and non-selectively ingests phytoplankton, zooplankton, and detritus (Moyle, 1976). Other more exotic species, such as the Nile tilapia (Tilapia nilotica) and silver carp (Hypothalmichthys molitrix), are phytophagous fish reported to ingest blue-green algae (Schuytema, 1977), but little is known about their interactions with endemic fish species and impacts should these species escape from introduction sites. The threadfin shad, already well established in California, should offer little concern for escape and negative

interactions with other endemic species. Increased pressure from threadfin shad to maintain smaller species of zooplankton should not be of concern, since zooplankton probably are not effective regulators of phytoplankton composition or abundance in Morris Reservoir.

Environmental manipulation may favor more desirable species of algae while reducing populations of noxious species. Blue-green algae have optimum growth at high pH but low carbon dioxide and chlorine levels. Additions of hydrochloric acid, carbon dioxide, and chlorine have shifted domination of phytoplankton communities from blue-green algae to green algae (Schuytema, 1977). Zooplankton regulation of phytoplankton would be more effective in a community dominated by green algae. Elimination of zooplanktivorous fish would favor larger species of zooplankton that are capable of ingesting larger species of phytoplankton and have a higher consumption rate. However, acidification of a lake may allow dissolution of toxic metals contained in bottom sediments. Environmental manipulation cannot be recommended as an effective management technique until data are developed from additional experimental applications.

Algacides

A large variety of inorganic and organic compounds are available for control of algae in bodies of water, but most are not allowed for use in potable water supplies (Dunst et al., 1974). Copper sulfate is the most widely used inorganic compound for algae control in potable water supplies. Toxicity to algae of copper sulfate is due to soluble copper ions, which are affected by water hardness and pH. Copper sulfate is ineffective as an algacide below depths of about 2 feet in lakes with total methyl orange alkalinities greater than about 50 mg/L as $CaCO_3$, since precipitation as copper carbonate removes copper from solution (Palmer, 1977). A copper sulfate dosage of 5.4 pounds per surface acre is recommended for lakes with high total alkalinities.

Species of algae vary in susceptibility to copper sulfate (Table 10). Most of the algae in Morris Reservoir known to cause taste and odor problems are susceptible to copper sulfate treatment, but several are not susceptible, including Scenedesmus, which occasionally dominates the phytoplankton community possibly as a result of toxic inhibition to other species by copper sulfate. Certain algae, particularly Aphanizomenon, can acquire increased tolerance to copper ions as a result of long-term exposure (Mackenthum, 1961).

Adverse effects to fish from normal treatment dosages have not been found, but zooplankton have been found to be more susceptible than algae to copper sulfate (Cooke et al., 1986). Copper levels near the surface of treated water bodies usually return to pretreatment levels within 8 to 10 days, followed by increases in algal biomass within 1 to 2 weeks (Whitaker et al., 1978). Algal blooms following treatment are often larger than pretreatment blooms, which may be due to abundant nutrient availability from decomposition in the epilimnion of large quantities of organic materials and severe reduction in numbers of herbivorous zooplankton. Further decomposition in the hypolimnion of organic materials settling from the epilimnion enhances oxygen depletion. Copper accumulates in bottom sediments, while sulfate from copper sulfate treatment forms hydrogen sulfide in the anoxic hypolimnion. Hydrogen sulfide binds with iron to form the insoluble ferrous sulfide precipitate, which

Table 10. Relative toxicity of copper sulfate to algae found in Morris Reservoir (from Palmer, 1977)

Group	Very Susceptible	Susceptible	Resistant	Very Resistant
Myxophyceae (blue-greens)	Anabaena* Aphanizomenon* Gomphosphaeria*			
Chlorophyceae (greens)			Chlamydomonas* Golenkinia Staurastrum*	Ankistrodesmus Elakatothrix Scenedesmus*
Bacillariophyceae (diatoms)	Asterionella* Cyclotella* Fragilaria* Melosira*	Gomphonema Navicula Synedra*		
Chrysophyceae (golden-browns)	Dinobryon*			
Cryptophyceae (cryptomonads)		Cryptomonas*		

* Algae known to cause taste and odor problems in water supply reservoirs.

uncouples the iron-phosphorus cycle to allow increased availability of phosphorus in surface waters following destratification and stimulation of phytoplankton production.

Conjunctive Use of Ground and Surface Water

Recommendations were made to blend water from the Park Well with that from Morris Reservoir to reduce to acceptable levels the high arsenic, iron, and manganese concentrations from the Park Well and the turbidity from Morris Reservoir, as well as to augment water supplies (DWR, 1987). Analyses of water samples collected from the Park Well in September 1986 found 0.122 mg/L of arsenic, 1.1 mg/L of iron, 3.21 mg/L of manganese, 379 mg/L total dissolved solids, and 308 mg/L as calcium carbonate hardness. Drinking water criteria for metals are 0.05 mg/L for arsenic and manganese, and 0.3 mg/L for iron (DHS, 1977). A limit of 250 mg/L for total dissolved solids is recommended because of possible adverse physiological effects and unpalatable mineral tastes (USEPA, 1986). Hardness affects scale formation in water heaters and plumbing, and soap requirements for cleaning. Water from the well is classified as very hard, which would indicate severe scale formation problems and increased soap requirements. Turbidity was not determined from the water samples collected from the well, but would be expected to be near zero. A criterion of 5 NTU has been established (DHS, 1977).

Water delivered to the Water Treatment Plant from Morris Reservoir also contained elevated concentrations of several elements. Iron concentrations ranged from 0.161 to 1.26 mg/L, with highest values reported from winter samples. Manganese concentrations ranged from 0.003 to 0.438 mg/L and exceeded the criterion in every month except February, March, and April. Hardness ranged from 53 to 165 mg/L as calcium carbonate, with highest levels occurring during the summer. Turbidity at the Water Treatment Plant ranged from 1.1 to 20 NTU, with highest levels corresponding to winter runoff.

The required dilution of well water to acceptable levels of contaminants would be greatest for manganese, requiring one part of well water and at least 63 parts of uncontaminated water. However, water from Morris Reservoir also exceeded the criterion for manganese in all but three months, and thus would not be suitable to reduce manganese contamination in the well water to acceptable levels. During the three months that manganese levels were acceptable in water from Morris Reservoir, iron concentrations exceeded the criteria, and thus reservoir water would not be suitable for reducing iron concentrations in the well water to acceptable limits. Arsenic levels in the Park Well, however, could be reduced to acceptable levels with a dilution of one part of well water to as little as 1.5 parts of water from Morris Reservoir. Reduction of turbidity levels in water from Morris Reservoir would require several volumes of well water to each one of reservoir water, which would result in inadequate dilution of arsenic, iron, and manganese contained in the well water. Elimination of detectable odor in water from the reservoir did not occur until more than eight parts of odor-free water (Red Bluff tap water) were used to dilute one part of reservoir water. Inadequate dilution of contaminants in the well water would occur at the dilution ratio required to eliminate odors in water from Morris Reservoir. The high concentrations of iron and manganese contained in water from both Morris Reservoir and the Park Well make conjunctive use infeasible without further treatment at either the Park Well or the Water Treatment Plant.

RECOMMENDATIONS

Management of Morris Reservoir to improve water quality will necessitate the management of nutrients that allow development of large populations of phytoplankton, which directly produce tastes and odors and lead to further degradation of water quality through decomposition and the development of hypolimnetic anoxia, solubilization of metals and nutrients from sediments, and production of hydrogen sulfide. Nutrient sources both external and internal to Morris Reservoir must be controlled. External nutrient sources are primarily organic and inorganic input from the watershed. Watershed disturbance should be minimized to reduce nutrient inputs from silt and organic debris. Unavoidable disturbance should be adequately rehabilitated to prevent translocation of nutrients from the watershed to Morris Reservoir. Rehabilitation of roads to prevent gulley erosion, installation of sediment basins, organic debris control through slash removal, and revegetation through hydroseeding and planting of woody vegetation on disturbed soils are techniques that should be employed to minimize effects from distrubance in the watershed.

Management of internal nutrient sources must concentrate on reducing nutrient levels through export and disruption of recycling from the sediments. Outlet facilities from the dam should be modified to allow releases to Davis Creek of water high in suspended sediment and nutrient loads from the bottom of the reservoir during winter, while releasing less turbid water from the surface to the Water Treatment Plant. Use of Davis Creek as the conduit from Morris Reservoir to the Water Treatment Plant during the summer would allow natural aeration and purification processes to enhance the quality of the water through aerobic decomposition of organic materials, dissipation of hydrogen sulfide, and precipitation of metals responsible for taste and odor problems.

Oxygen should be maintained in the hypolimnion through hypolimnetic aeration or aeration-circulation to prevent formation of hydrogen sulfide and solubilization of metals and nutrients. Suspension in cloth bags at the surface of blocks of aluminum chloride hexahydrate or ferric chloride hexahydrate would allow precipitation and removal from the epilimnion of phosphorus, reduce algal growth while favoring a shift from blue-green algae to green algae, and decrease oxygen demands for decomposition in the hypolimnion of organic materials produced in the epilimnion. Stocking of phytophagous fish, such as threadfin shad, may be desirable to further control phytoplankton populations.

Present treatment methods at Morris Reservoir have not been effective in controlling taste and odor problems. Hypolimnetic pumping has done little except maintain a nutrient supply in the epilimnion for continued algal growth. Copper sulfate treatment, though widely accepted for phytoplankton control, has not benefited water quality in Morris Reservoir and has several drawbacks. Algal blooms subsequent to copper sulfate treatment are likely, since copper quickly precipitates and nutrients are regenerated in the epilimnion from decomposing algae. Sudden influx of large quantities of organic material in the hypolimnion contributes to oxygen depletion, which is followed by solubilization of metals and nutrients. Hydrogen sulfide is generated from anoxic reduction of sulfate, which contributes odor and forms a precipitate with iron that allows increased concentrations of phosphorus to remain in solution following lake turnover. Increased nutrient levels allow greater phytoplankton production during the next production cycle. Discontinued use of both the hypolimnetic pump and copper sulfate treatment are recommended.

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APPENDIX 1A. PHYSICAL WATER QUALITY CHARACTERISTICS OF MORRIS RESERVOIR NEAR THE DAM

Date	Depth m	Depth ft	Temperature °C	Temperature °F	D.O.[1/] (mg/L)	D.O.[1/] (% Sat.)	Alkalinity (mg $CaCO_3$/L)	Color (APHA Units)	EC[2/] (umhos/cm)	Odor[3/]	pH Field	pH Lab	Turbidity (NTU)
04/24/86	0	0.0	16.4	61.5	8.9	95	83	-	177	0	7.3	7.9	0.4
	1	3.3	16.2	61.2	9.0	96	-	-	-	-	-	-	-
	2	6.6	15.8	60.4	9.4	99	-	-	-	-	-	-	-
	3	9.8	15.0	59.0	9.3	97	87	-	194	0	7.3	8.0	0.4
	4	13.1	14.0	57.2	9.4	96	-	-	-	-	-	-	-
	5	16.4	12.8	55.0	9.1	97	-	-	-	-	-	-	-
	6	19.7	10.8	51.4	7.2	90	69	-	159	0	7.1	8.0	1.0
	7	23.0	9.8	49.6	6.7	62	-	-	-	-	-	-	-
	8	26.3	9.0	48.2	6.3	57	-	-	-	-	-	-	-
	9	29.5	8.8	47.8	5.6	51	46	-	114	0	6.9	7.9	6.0
	10	32.8	8.6	47.5	4.8	43	-	-	-	-	-	-	-
	11	36.1	8.6	47.5	4.6	41	-	-	-	-	-	-	-
	12	39.4	8.6	47.5	3.8	34	52	-	121	0	6.9	7.9	11.0
	13	42.7B[4/]	8.6	47.5	1.3	12	-	-	-	-	-	-	-
	Secchi depth: 3 m (9.7 ft)												
05/21/86	0	0.0	19.0	66.2	8.8	99	94	-	199	0	7.4	8.1	0.6
	1	3.3	19.0	66.2	8.7	98	-	-	-	-	-	-	-
	2	6.6	18.8	65.8	8.7	98	-	-	-	-	-	-	-
	3	9.8	18.0	65.8	10.9	121	97	-	207	0	7.4	8.0	0.7
	4	13.1	16.4	61.5	10.8	116	-	-	-	-	-	-	-
	5	16.4	14.9	58.8	10.2	106	-	-	-	-	-	-	-
	6	19.7	12.9	55.2	6.3	63	90	-	193	0	7.2	7.9	0.7
	7	23.0	11.6	52.9	3.4	33	-	-	-	-	-	-	-
	8	26.3	10.5	50.9	1.7	16	-	-	-	-	-	-	-
	9	29.5	9.8	49.6	0.6	6	56	-	124	0	6.8	7.6	2.0
	10	32.8	9.5	49.1	0	0	-	-	-	-	-	-	-
	11	36.1	9.3	48.7	0	0	-	-	-	-	-	-	-
	12	39.4	9.3	48.7	0	0	56	-	124	0	6.7	7.3	4.5
	13	42.7	9.2	48.6	0	0	-	-	-	-	-	-	-
	13.3	43.7B[4/]	9.2	48.6	0	0	-	-	-	-	-	-	-
	Secchi depth: 3.3 m (10.8 ft)												

1/ Dissolved oxygen in milligrams per liter (mg/L) or percent saturation (% Sat.)
2/ Electrical conductivity
3/ (0) none detected, (+) slight odor, (++) strong odor
4/ Bottom

APPENDIX 1A. PHYSICAL WATER QUALITY CHARACTERISTICS OF MORRIS RESERVOIR NEAR THE DAM (Continued)

Date	Depth m	Depth ft	Temperature °C	Temperature °F	D.O.[1] (mg/L)	D.O.[1] (% Sat.)	Alkalinity (mg $CaCO_3$/L)	Color (APHA Units)	EC[2] (umhos/cm)	Odor[3]	pH Field	pH Lab	Turbidity (NTU)
06/05/86	0	0.0	22.2	72.0	8.3	100	96	-	200	0	7.6	7.9	0.4
	1	3.3	22.2	72.0	8.2	99	-	-	-	-	-	-	-
	2	6.6	22.2	72.0	8.2	98	-	-	-	-	-	-	-
	3	9.8	21.8	71.2	8.6	102	98	-	199	0	7.6	7.9	0.9
	4	13.1	19.9	67.8	10.9	125	-	-	-	-	-	-	-
	5	16.4	17.4	63.3	11.1	121	-	-	-	-	-	-	-
	6	19.7	14.9	58.8	8.3	86	93	-	196	0	7.3	7.8	0.6
	7	23.0	13.4	56.1	4.3	43	-	-	-	-	-	-	-
	8	26.3	11.6	52.9	1.2	12	-	-	-	-	-	-	-
	9	29.5	10.8	51.4	0	0	63	-	134	0	6.6	7.2	1.4
	10	32.8	10.3	50.5	0	0	-	-	-	-	-	-	-
	11	36.1	10.2	50.1	0	0	-	-	-	-	-	-	-
	12	39.4	9.9	49.8	0	0	59	-	127	0	6.6	7.3	3.1
	13	42.7B[4]	9.6	49.3	0	0	-	-	-	-	-	-	-
Secchi depth: 2.7 m (8.9 ft)													
06/11/86	0	0.0	23.2	73.8	9.0	110	-	-	-	-	-	-	-
	1	3.3	22.6	72.7	8.8	106	-	-	-	-	-	-	-
	2	6.6	22.0	71.6	9.6	115	-	-	-	-	-	-	-
	3	9.8	21.3	70.3	10.7	126	-	-	-	-	-	-	-
	4	13.1	20.2	68.4	11.2	129	-	-	-	-	-	-	-
	5	16.4	18.3	64.9	12.0	134	-	-	-	-	-	-	-
	6	19.7	16.1	61.0	8.6	92	-	-	-	-	-	-	-
	7	23.0	13.6	56.5	5.3	53	-	-	-	-	-	-	-
	8	26.3	12.2	54.0	1.4	14	-	-	-	-	-	-	-
	9	29.5	11.4	52.5	0	0	-	-	-	-	-	-	-
	10	32.8	10.8	51.4	0	0	-	-	-	-	-	-	-
	11	36.1	10.4	50.7	0	0	-	-	-	-	-	-	-
	12	39.4	10.3	50.5	0	0	-	-	-	-	-	-	-
	13	42.7B[4]	9.9	49.8	0	0	-	-	-	-	-	-	-
Secchi depth: -													

APPENDIX 1A. PHYSICAL WATER QUALITY CHARACTERISTICS OF MORRIS RESERVOIR NEAR THE DAM (Continued)

Date	Depth m	Depth ft	Temperature °C	Temperature °F	D.O.[1] (mg/L)	D.O.[1] (% Sat.)	Alkalinity (mg $CaCO_3$/L)	Color (APHA Units)	EC[2] (umhos/cm)	Odor[3]	pH Field	pH Lab	Turbidity (NTU)
06/18/86	0	0.0	22.3	72.1	10.0	120	104	-	223	0	7.8	7.9	1.2
	1	3.3	22.2	72.0	10.0	120	-	-	-	-	-	-	-
	2	6.6	21.9	71.4	9.9	118	-	-	-	-	-	-	-
	3	9.8	21.7	71.1	10.0	119	104	-	223	0	7.8	7.9	1.7
	4	13.1	21.2	70.2	11.0	130	-	-	-	-	-	-	-
	5	16.4	19.6	67.3	11.6	133	-	-	-	-	-	-	-
	6	19.7	16.6	61.9	6.2	67	99	-	216	0	7.2	7.6	0.8
	7	23.0	14.3	57.7	2.0	20	-	-	-	-	-	-	-
	8	26.3	12.7	54.9	0.8	8	-	-	-	-	-	-	-
	9	29.5	11.8	53.2	0	0	70	-	159	0	6.8	7.0	1.2
	10	32.8	11.2	52.2	0	0	-	-	-	-	-	-	-
	11	36.1	10.9	51.6	0	0	-	-	-	-	-	-	-
	12	39.4	10.7	51.3	0	0	67	-	149	0	6.8	7.0	2.3
	13	42.7B[4]	10.2	50.4	0	0	-	-	-	-	-	-	-
Secchi depth: 2.1 m (6.9 ft)													
07/09/86	0	0.0	24.9	76.8	8.0	101	106	-	239	0	7.9	7.9	0.8
	1	3.3	24.3	75.4	7.6	95	-	-	-	-	-	-	-
	2	6.6	24.0	75.2	6.8	84	-	-	-	-	-	-	-
	3	9.8	23.6	74.5	6.1	75	108	-	240	0	7.6	7.8	0.8
	4	13.1	23.2	73.8	5.9	72	-	-	-	-	-	-	-
	5	16.4	22.0	71.6	6.6	79	-	-	-	-	-	-	-
	6	19.7	18.4	65.1	3.2	36	102	-	229	0	7.0	7.3	1.6
	7	23.0	16.2	61.2	0	0	-	-	-	-	-	-	-
	8	26.3	14.3	57.7	0	0	-	-	-	-	-	-	-
	9	29.5	13.3	55.9	0	0	85	-	190	+	6.9	7.1	1.2
	10	32.8	12.7	54.9	0	0	-	-	-	-	-	-	-
	11	36.1	12.2	54.0	0	0	-	-	-	-	-	-	-
	12	37.4	11.7	53.1	0	0	82	-	179	++	6.9	6.9	3.3
	12.5	41.3B[4]	11.2	52.2	0	0	-	-	-	-	-	-	-
Secchi depth: 2.9 m (9.5 ft)													

APPENDIX 1A. PHYSICAL WATER QUALITY CHARACTERISTICS OF MORRIS RESERVOIR NEAR THE DAM (Continued)

Date	Depth m	Depth ft	Temperature °C	Temperature °F	D.O.[1] (mg/L)	D.O.[1] (% Sat.)	Alkalinity (mg $CaCO_3$/L)	Color (APHA Units)	EC[2] (umhos/cm)	Odor[3]	pH Field	pH Lab	Turbidity (NTU)
07/16/86	0	0.0	24.7	76.5	7.6	96	-	-	-	-	-	-	-
	1	3.3	24.7	76.5	7.8	98	-	-	-	-	-	-	-
	2	6.6	24.6	76.3	7.8	98	-	-	-	-	-	-	-
	3	9.9	24.4	75.9	7.8	98	-	-	-	-	-	-	-
	4	13.1	23.9	75.0	7.6	94	-	-	-	-	-	-	-
	5	16.4	22.8	73.0	13.0	158	-	-	-	-	-	-	-
	6	14.7	19.9	67.8	6.7	77	-	-	-	-	-	-	-
	7	23.0	16.6	61.9	0	0	-	-	-	-	-	-	-
	8	26.3	15.0	59.0	0	0	-	-	-	-	-	-	-
	9	29.5	14.2	57.6	0	0	-	-	-	-	-	-	-
	10	32.8	13.3	55.9	0	0	-	-	-	-	-	-	-
	11	36.1	13.0	55.4	0	0	-	-	-	-	-	-	-
	12	41.3B[4]	11.9	53.4	0	0	-	-	-	-	-	-	-
Secchi depth: -													
07/24/86	0	0.0	25.8	78.4	7.6	97	109	-	251	0	7.6	7.9	0.7
	1	3.3	25.6	78.1	7.6	97	-	-	-	-	-	-	-
	2	6.6	24.8	76.6	7.6	96	-	-	-	-	-	-	-
	3	9.9	24.6	76.3	7.6	95	110	-	250	0	7.6	7.9	0.9
	4	13.1	24.2	75.6	8.3	103	-	-	-	-	-	-	-
	5	16.4	23.8	74.8	8.8	109	-	-	-	-	-	-	-
	6	19.7	20.7	69.3	5.2	61	105	-	239	0	7.0	7.4	2.5
	7	23.0	17.2	63.0	0.0	0	-	-	-	-	-	-	-
	8	26.3	16.2	61.2	0.0	0	-	-	-	-	-	-	-
	9	29.5	15.0	59.0	0.0	0	92	-	205	+	7.0	7.2	1.4
	10	32.8	14.3	57.7	0.0	0	-	-	-	-	-	-	-
	11	36.1	13.7	56.7	0.0	0	-	-	-	-	-	-	-
	12	39.4B[4]	12.2	54.0	0.0	0	92	-	205	++	6.8	7.1	2.7
Secchi depth: 2.3 m (7.5 ft)													

APPENDIX 1A. PHYSICAL WATER QUALITY CHARACTERISTICS OF MORRIS RESERVOIR NEAR THE DAM (Continued)

Date	Depth m	Depth ft	Temperature °C	Temperature °F	D.O.[1] (mg/L)	D.O.[1] (% Sat.)	Alkalinity (mg $CaCO_3$/L)	Color (APHA Units)	EC[2] (umhos/cm)	Odor[3]	pH Field	pH Lab	Turbidity (NTU)
08/07/86	0	0.0	25.8	78.4	7.6	97	114	-	259	0	7.7	7.7	1.2
	1	3.3	25.7	78.3	7.6	97	-	-	-	-	-	-	-
	2	6.6	25.3	77.5	7.4	94	-	-	-	-	-	-	-
	3	9.9	25.1	77.2	7.4	94	114	-	260	0	7.7	7.7	1.6
	4	13.1	24.7	76.5	7.6	96	-	-	-	-	-	-	-
	5	16.4	24.1	75.4	7.4	92	-	-	-	-	-	-	-
	6	19.7	22.2	72.0	5.6	67	108	-	253	0	7.2	7.6	1.5
	7	23.0	20.4	68.7	0.5	6	-	-	-	-	-	-	-
	8	26.3	18.0	64.4	0.0	0	-	-	-	-	-	-	-
	9	29.5	16.8	62.2	0.0	0	101	-	226	+	6.9	7.4	2.3
	10	32.8	16.2	61.2	0.0	0	-	-	-	-	-	-	-
	11	36.1	14.8	58.6	0.0	0	99	-	228	++	6.8	7.1	2.7
	11.5	40.0B[4]	13.5	56.3	0.0	0	-	-	-	-	-	-	-
Secchi depth: 1.7 m (5.6 ft)													
08/14/86	0	0.0	25.8	78.4	7.1	91	-	-	-	-	-	-	-
	1	3.3	25.3	77.5	6.9	88	-	-	-	-	-	-	-
	2	6.6	25.2	77.4	6.9	88	-	-	-	-	-	-	-
	3	9.9	25.1	77.2	6.7	85	-	-	-	-	-	-	-
	4	13.1	24.8	76.6	6.2	78	-	-	-	-	-	-	-
	5	16.4	24.5	76.1	6.2	78	-	-	-	-	-	-	-
	6	19.7	22.8	73.0	1.8	22	-	-	-	-	-	-	-
	7	23.0	21.2	70.2	0	0	-	-	-	-	-	-	-
	8	26.3	19.6	67.3	0	0	-	-	-	-	-	-	-
	9	29.5	18.3	64.9	0	0	-	-	-	-	-	-	-
	10	32.8	17.4	63.3	0	0	-	-	-	-	-	-	-
	11	36.1	14.8	58.6	0	0	-	-	-	-	-	-	-
	11.5	40.0B[4]	14.3	57.7	0	0	-	-	-	-	-	-	-
Secchi depth: -													

APPENDIX 1A. PHYSICAL WATER QUALITY CHARACTERISTICS OF MORRIS RESERVOIR NEAR THE DAM (Continued)

Date	Depth m	Depth ft	Temperature °C	Temperature °F	D.O.[1] (mg/L)	D.O.[1] (% Sat.)	Alkalinity (mg $CaCO_3$/L)	Color (APHA Units)	EC[2] (umhos/cm)	Odor[3]	pH Field	pH Lab	Turbidity (NTU)
08/21/86	0	0.0	24.9	76.8	7.7	97	112	15	265	0	7.5	7.8	1.5
	1	3.3	24.4	75.9	7.6	95	–	–	–	–	–	–	–
	2	6.6	24.1	75.4	7.3	91	–	–	–	–	–	–	–
	3	9.9	23.9	75.0	6.8	84	115	15	268	0	7.5	7.7	1.7
	4	13.1	23.8	74.8	6.1	75	–	–	–	–	–	–	–
	5	16.4	23.8	74.8	4.6	57	–	–	–	–	–	–	–
	6	19.7	23.4	74.1	2.6	32	118	15	269	0	7.2	7.5	1.7
	7	23.0	21.8	71.2	0	0	–	–	–	–	–	–	–
	8	26.3	20.2	68.4	0	0	–	–	–	–	–	–	–
	9	29.5	19.5	67.1	0	0	118	50	253	+	6.8	7.1	3.8
	10	32.8	18.2	64.8	0	0	–	–	–	–	–	–	–
	10.5	34.6	–	–	0	0	119	60	255	++	6.8	7.0	7.7
	11	36.1B[4]	15.2	59.4	0	0	–	–	–	–	–	–	–

Secchi depth: 2.0 m (6.7 ft)

09/11/86	0	0.0	24.8	76.6	8.8	110	130	20	272	0	7.8	7.8	3.0
	1	3.3	24.9	76.8	8.7	110	–	–	–	–	–	–	–
	2	6.6	21.9	71.4	3.8	45	–	–	–	–	–	–	–
	3	9.9	21.7	71.1	4.0	48	130	20	277	0	7.3	7.6	2.5
	4	13.1	21.6	70.9	4.2	50	–	–	–	–	–	–	–
	5	16.4	21.6	70.9	4.4	52	–	–	–	–	–	–	–
	6	19.7	21.5	70.7	5.4	64	130	20	267	0	7.3	7.6	2.0
	7	23.0	21.4	70.5	5.5	65	–	–	–	–	–	–	–
	8	26.3	21.4	70.5	5.5	65	–	–	–	–	–	–	–
	9	29.5	21.4	70.5	4.2	50	–	–	–	–	–	–	–
	9.5	31.2	–	–	–	–	133	20	279	0	7.2	7.3	4.0
	10	32.8	18.6	65.5	0.2	2	–	–	–	–	–	–	–
	10.2	33.5B[4]	18.4	65.1	0	0	–	–	–	–	–	–	–

Secchi depth: 1.0 m (3.3 ft)

APPENDIX 1A. PHYSICAL WATER QUALITY CHARACTERISTICS OF MORRIS RESERVOIR NEAR THE DAM (Continued)

Date	Depth m	Depth ft	Temperature °C	Temperature °F	D.O.[1] (mg/L)	D.O.[1] (% Sat.)	Alkalinity (mg $CaCO_3$/L)	Color (APHA Units)	EC[2] (umhos/cm)	Odor[3]	pH Field	pH Lab	Turbidity (NTU)
09/25/86	0	0.0	17.5	63.5	6.8	75	127	-	282	0	7.5	7.7	1.8
	1	3.3	17.3	63.1	6.6	72	-	-	-	-	-	-	-
	2	6.6	17.1	62.8	5.6	61	-	-	-	-	-	-	-
	3	9.9	17.0	62.6	5.9	64	130	-	282	0	7.4	7.7	2.9
	4	13.1	16.9	62.4	5.9	64	-	-	-	-	-	-	-
	5	16.4	16.9	62.4	5.9	64	-	-	-	-	-	-	-
	6	19.7	16.9	62.4	5.9	64	122	-	282	0	7.3	7.6	3.2
	7	23.0	16.8	62.2	5.9	64	-	-	-	-	-	-	-
	8	26.3	16.8	62.2	5.8	63	-	-	-	-	-	-	-
	9	29.5	16.8	62.2	5.7	62	128	-	282	0	7.3	7.6	4.7
	9.8	32.0B[4]	16.9	62.4	5.4	58	126	-	283	0	7.3	7.6	9.2
	Secchi depth: 2.1 m (6.7 ft)												
10/10/86	0	0.0	20.7	69.3	10.0	117	130	15	289	0	8.0	7.9	1.9
	1	3.3	18.2	64.8	10.8	120	-	-	-	-	-	-	-
	2	6.6	17.3	63.1	10.7	117	-	-	-	-	-	-	-
	3	9.9	17.2	63.0	7.5	82	127	15	291	0	7.4	7.7	1.4
	4	13.1	16.8	62.2	4.3	46	-	-	-	-	-	-	-
	5	16.4	16.3	61.3	2.5	27	-	-	-	-	-	-	-
	6	19.7	16.3	61.3	2.5	27	127	20	291	0	7.2	7.5	1.9
	7	23.0	16.2	61.2	2.2	23	-	-	-	-	-	-	-
	8	26.3	16.1	61.0	0.8	9	-	-	-	-	-	-	-
	9	29.5	16.0	60.8	0	0	130	30	294	0	7.2	7.5	4.0
	9.3	30.5B[4]	16.0	60.8	0	0	-	-	-	-	-	-	-
	Secchi depth: 1.5 m (4.9 ft)												

APPENDIX 1A. PHYSICAL WATER QUALITY CHARACTERISTICS OF MORRIS RESERVOIR NEAR THE DAM (Continued)

Date	Depth m	Depth ft	Temperature °C	Temperature °F	D.O.[1] (mg/L)	D.O.[1] (% Sat.)	Alkalinity (mg $CaCO_3$/L)	Color (APHA Units)	EC[2] (umhos/cm)	Odor[3]	pH Field	pH Lab	Turbidity (NTU)
10/16/86	0	0.0	16.8	62.2	5.7	62	-	-	-	-	-	-	-
	1	3.3	16.3	61.3	5.5	59	-	-	-	-	-	-	-
	2	6.6	16.3	61.3	4.0	43	-	-	-	-	-	-	-
	3	9.9	16.2	61.2	1.4	15	-	-	-	-	-	-	-
	4	13.1	16.2	61.2	1.4	15	-	-	-	-	-	-	-
	5	16.4	16.1	61.0	3.7	39	-	-	-	-	-	-	-
	6	19.7	16.1	61.0	4.7	50	-	-	-	-	-	-	-
	7	23.0	16.1	61.0	5.5	59	-	-	-	-	-	-	-
	8	26.3	16.1	61.0	1.8	19	-	-	-	-	-	-	-
	9	29.5B[4]	16.0	60.8	1.4	15	-	-	-	-	-	-	-
Secchi depth: -													
10/24/86	0	0.0	15.1	59.2	8.8	92	133	20	285	0	7.9	8.1	2.5
	1	3.3	15.1	59.2	8.7	91	-	-	-	-	-	-	-
	2	6.6	15.1	59.2	8.6	90	-	-	-	-	-	-	-
	3	9.9	15.1	59.2	8.6	90	132	20	284	0	7.9	8.1	2.6
	4	13.1	15.1	59.2	8.6	90	-	-	-	-	-	-	-
	5	16.4	15.1	59.2	8.6	90	-	-	-	-	-	-	-
	6	19.7	15.1	59.2	8.3	87	134	20	290	0	7.8	8.1	3.9
	7	23.0	15.0	59.0	8.2	85	-	-	-	-	-	-	-
	8	26.3	15.0	59.0	8.3	86	-	-	-	-	-	-	-
	9	29.5B[4]	15.0	59.0	7.8	81	133	30	286	0	7.1	8.0	8.0
Secchi depth: 0.8 m (2.4 ft)													

APPENDIX 1A. PHYSICAL WATER QUALITY CHARACTERISTICS OF MORRIS RESERVOIR NEAR THE DAM (Continued)

Date	Depth m	Depth ft	Temperature °C	Temperature °F	D.O.[1] (mg/L)	D.O.[1] (% Sat.)	Alkalinity (mg $CaCO_3$/L)	Color (APHA Units)	EC[2] (umhos/cm)	Odor[3]	pH Field	pH Lab	Turbidity (NTU)
11/06/86	0	0.0	14.0	57.2	5.0	51	137	-	291	0	7.3	8.0	3.0
	1	3.3	13.4	56.1	4.7	47	-	-	-	-	-	-	-
	2	6.6	13.3	55.9	4.7	47	-	-	-	-	-	-	-
	3	9.9	13.3	55.9	4.7	47	137	-	293	0	7.3	8.0	4.0
	4	13.1	13.2	55.8	4.7	47	-	-	-	-	-	-	-
	5	16.4	13.2	55.8	4.7	47	-	-	-	-	-	-	-
	6	19.7	13.2	55.8	4.7	47	136	-	290	0	7.3	8.0	3.9
	7	23.0	13.2	55.8	4.8	47	-	-	-	-	-	-	-
	8	26.3	13.2	55.8	4.9	49	-	-	-	-	-	-	-
	8.5	27.9	-	-	-	-	136	-	298	0	7.4	8.2	3.6
	9	29.5B[4]	13.2	55.8	4.0	40	-	-	-	-	-	-	-
	Secchi depth: 0.9 m (3.0 ft)												
11/13/86	0	0.0	12.1	53.4	8.1	79	-	-	-	-	-	-	-
	1	3.3	11.8	53.2	7.6	74	-	-	-	-	-	-	-
	2	6.6	11.4	52.5	7.6	73	-	-	-	-	-	-	-
	3	9.9	11.3	52.3	7.5	72	-	-	-	-	-	-	-
	4	13.1	11.3	52.3	7.4	71	-	-	-	-	-	-	-
	5	16.4	11.3	52.3	7.2	69	-	-	-	-	-	-	-
	6	19.7	11.2	52.2	7.4	71	-	-	-	-	-	-	-
	7	23.0	11.2	52.2	7.6	73	-	-	-	-	-	-	-
	8	26.3	11.2	52.2	6.6	63	-	-	-	-	-	-	-
	8.8	28.9B[4]	11.2	52.2	6.3	60	-	-	-	-	-	-	-
	Secchi depth: -												

APPENDIX 1A. PHYSICAL WATER QUALITY CHARACTERISTICS OF MORRIS RESERVOIR NEAR THE DAM (Continued)

Date	Depth m	Depth ft	Temperature °C	Temperature °F	D.O.[1] (mg/L)	D.O.[1] (% Sat.)	Alkalinity (mg $CaCO_3$/L)	Color (APHA Units)	EC[2] (umhos/cm)	Odor[3]	pH Field	pH Lab	Turbidity (NTU)
11/21/86	0	0.0	11.9	53.4	9.1	88	138	-	295	0	7.3	7.8	2.8
	1	3.3	11.7	53.1	8.6	83	-	-	-	-	-	-	-
	2	6.6	11.4	52.5	8.4	81	-	-	-	-	-	-	-
	3	9.9	11.2	52.2	7.2	69	137	-	294	0	7.3	7.7	3.2
	4	13.1	11.1	52.0	6.7	64	-	-	-	-	-	-	-
	5	16.4	11.0	51.8	6.5	62	-	-	-	-	-	-	-
	6	19.7	11.0	51.8	6.4	61	137	-	294	0	7.3	7.6	3.8
	7	23.0	11.0	51.8	6.2	59	-	-	-	-	-	-	-
	8	26.3	11.0	51.8	6.0	57	137	-	294	0	7.2	7.7	5.8
	8.1	26.6B[4]	11.0	51.8	5.7	54	-	-	-	-	-	-	-
	Secchi depth: 0.9 m (3.0 ft)												
12/11/86	0	0.0	7.8	46.0	9.3	82	141	20	306	0	7.4	7.8	3.0
	1	3.3	7.7	45.9	9.2	81	-	-	-	-	-	-	-
	2	6.6	7.6	45.7	9.2	81	-	-	-	-	-	-	-
	3	9.9	7.5	45.5	9.2	81	142	20	310	0	7.4	7.7	4.6
	4	13.1	7.4	45.3	9.2	80	-	-	-	-	-	-	-
	5	16.4	7.4	45.3	9.2	80	-	-	-	-	-	-	-
	6	19.7	7.3	45.1	9.2	80	142	20	311	0	7.3	7.7	4.3
	7	23.0	7.3	45.1	9.2	80	-	-	-	-	-	-	-
	7.5	24.6	7.3	45.1	-	-	142	30	317	0	-	7.8	13.0
	7.8	25.6B[4]	7.3	45.1	9.1	79	-	-	-	-	-	-	-
	Secchi depth: 0.9 m (3.0 ft)												

APPENDIX 1A. PHYSICAL WATER QUALITY CHARACTERISTICS OF MORRIS RESERVOIR NEAR THE DAM (Continued)

Date	Depth m	Depth ft	Temperature °C	Temperature °F	D.O.[1] (mg/L)	D.O.[1] (% Sat.)	Alkalinity (mg $CaCO_3$/L)	Color (APHA Units)	EC[2] (umhos/cm)	Odor[3]	pH Field	pH Lab	Turbidity (NTU)
12/23/86	0	0.0	7.9	46.2	10.3	91	131	30	292	0	7.4	7.8	5.6
	1	3.3	7.9	46.2	10.3	91	–	–	–	–	–	–	–
	2	6.6	7.8	46.0	10.2	90	–	–	–	–	–	–	–
	3	9.9	7.4	45.3	9.5	83	136	30	297	0	7.3	7.8	6.0
	4	13.1	7.3	45.1	9.5	83	–	–	–	–	–	–	–
	5	16.4	7.3	45.1	9.5	83	–	–	–	–	–	–	–
	6	19.7	7.3	45.1	9.6	84	135	30	297	0	7.3	7.7	6.3
	7	23.0	7.3	45.1	9.4	82	–	–	–	–	–	–	–
	8	26.3B[4]	7.3	45.1	9.4	82	136	40	298	0	7.3	7.8	15.0
Secchi depth: 0.7 m (2.3 ft)													
01/09/87	0	0.0	7.0	44.6	9.5	82	76	55	190	0	7.2	7.2	16
	1	3.3	7.0	44.6	9.5	82	–	–	–	–	–	–	–
	2	6.6	7.0	44.6	9.5	82	–	–	–	–	–	–	–
	3	9.9	7.0	44.6	9.5	82	76	55	190	0	7.1	7.2	16
	4	13.1	7.0	44.6	9.5	82	–	–	–	–	–	–	–
	5	16.4	7.0	44.6	9.5	82	–	–	–	–	–	–	–
	6	19.7	7.0	44.6	9.5	82	77	55	189	0	7.0	7.2	16
	7	23.0	7.0	44.6	9.5	82	–	–	–	–	–	–	–
	8	26.3	7.0	44.6	9.5	82	–	–	–	–	–	–	–
	9	29.5	6.9	44.4	9.4	81	77	55	192	0	7.2	7.2	16
	10	32.8	6.9	44.4	9.3	80	–	–	–	–	–	–	–
	11	36.1	6.9	44.4	9.3	80	81	55	198	0	7.1	7.2	16
	11.5	37.7B[4]	6.9	44.4	9.0	78	–	–	–	–	–	–	–
Secchi depth: 0.5 m (1.6 ft)													

APPENDIX 1A. PHYSICAL WATER QUALITY CHARACTERISTICS OF MORRIS RESERVOIR NEAR THE DAM (Continued)

Date	Depth m	Depth ft	Temperature °C	Temperature °F	D.O.[1] (mg/L)	D.O.[1] (% Sat.)	Alkalinity (mg $CaCO_3$/L)	Color (APHA Units)	EC[2] (umhos/cm)	Odor[3]	pH Field	pH Lab	Turbidity (NTU)
01/22/87	0	0.0	6.1	43.0	9.7	82	79	55	198	0	7.3	7.3	8.2
	1	3.3	6.1	43.0	9.7	82	-	-	-	-	-	-	-
	2	6.6	5.9	42.6	9.3	78	-	-	-	-	-	-	-
	3	9.9	5.8	42.4	9.2	77	79	55	201	0	7.3	7.2	9.0
	4	13.1	5.7	42.3	9.1	76	-	-	-	-	-	-	-
	5	16.4	5.7	42.3	9.1	76	-	-	-	-	-	-	-
	6	19.7	5.7	42.3	9.1	76	80	55	202	0	7.2	7.3	9.7
	7	23.0	5.7	42.3	9.1	76	-	-	-	-	-	-	-
	8	26.3	5.7	42.3	9.0	75	-	-	-	-	-	-	-
	9	29.5	5.7	42.3	9.0	75	82	55	206	0	7.2	7.3	9.5
	10	32.8	5.7	42.3	9.0	75	-	-	-	-	-	-	-
	11	36.1	5.7	42.3	9.0	75	84	55	209	0	7.2	7.3	10.0
	11.8	38.7B[4]	5.8	42.4	7.8	65	-	-	-	-	-	-	-
	Secchi depth: 1.0 m (3.3 ft)												
02/05/87	0	0.0	9.2	48.6	10.9	100	42	65	108	0	7.3	7.1	16
	1	3.3	7.5	45.5	10.7	94	-	-	-	-	-	-	-
	2	6.6	7.1	44.8	10.4	90	-	-	-	-	-	-	-
	3	9.9	6.9	44.4	10.2	88	58	65	143	0	7.2	7.3	12
	4	13.1	6.8	44.2	10.0	86	-	-	-	-	-	-	-
	5	16.4	6.6	43.8	9.6	82	-	-	-	-	-	-	-
	6	19.7	6.3	43.3	9.5	81	72	55	171	0	7.1	7.3	10
	7	23.0	6.3	43.3	9.1	77	-	-	-	-	-	-	-
	8	26.3	6.3	43.3	9.1	77	-	-	-	-	-	-	-
	9	29.5	6.2	43.2	8.9	75	74	55	175	0	7.1	7.4	10
	10	32.8	6.2	43.2	8.8	75	-	-	-	-	-	-	-
	11	36.1	6.2	43.2	8.8	75	-	-	-	-	-	-	-
	11.5	37.7	6.2	43.2	-	-	75	-	177	0	7.1	7.3	10
	12	39.4	6.2	43.2	8.2	70	-	-	-	-	-	-	-
	12.5	41.0B[4]	6.2	43.2	8.1	69	-	-	-	-	-	-	-
	Secchi depth: 0.5 m (1.8 ft)												

APPENDIX 1A. PHYSICAL WATER QUALITY CHARACTERISTICS OF MORRIS RESERVOIR NEAR THE DAM (Continued)

Date	Depth m	Depth ft	Temperature °C	Temperature °F	D.O.[1] (mg/L)	D.O.[1] (% Sat.)	Alkalinity (mg $CaCO_3$/L)	Color (APHA Units)	EC[2] (umhos/cm)	Odor[3]	pH Field	pH Lab	Turbidity (NTU)
02/18/87	0	0.0	8.3	46.9	9.9	88	41	80	107	0	7.1	7.1	21
	1	3.3	7.8	46.0	9.9	87	-	-	-	-	-	-	-
	2	6.6	7.7	45.9	9.9	87	-	-	-	-	-	-	-
	3	9.9	7.7	45.9	9.8	86	47	90	120	0	7.1	7.1	19
	4	13.1	7.7	45.9	9.6	85	-	-	-	-	-	-	-
	5	16.4	7.6	45.7	9.4	83	-	-	-	-	-	-	-
	6	19.7	7.4	45.3	8.9	78	61	90	147	0	7.1	7.1	18
	7	23.0	7.4	45.3	8.9	78	-	-	-	-	-	-	-
	8	26.3	7.1	44.8	8.6	75	-	-	-	-	-	-	-
	9	29.5	7.0	44.6	8.1	70	67	90	160	0	7.1	7.1	15
	10	32.8	7.0	44.6	8.0	69	-	-	-	-	-	-	-
	11	36.1	6.9	44.4	7.8	67	-	-	-	-	-	-	-
	12	39.4	6.9	44.4	7.5	65	69	90	164	0	7.1	7.1	17
	12.4	40.7B[4]	6.9	44.4	7.0	60	-	-	-	-	-	-	-
Secchi depth: 0.4 m (1.3 ft)													
03/04/87	0	0.0	8.7	47.7	10.0	90	49	70	126	0	7.2	7.2	12
	1	3.3	8.7	47.7	10.0	90	-	-	-	-	-	-	-
	2	6.6	8.7	47.7	10.0	90	-	-	-	-	-	-	-
	3	9.9	8.7	47.7	10.0	90	49	65	127	0	7.2	7.2	12
	4	13.1	8.7	47.7	10.1	91	-	-	-	-	-	-	-
	5	16.4	8.6	47.5	10.1	91	-	-	-	-	-	-	-
	6	19.7	8.6	47.5	10.0	90	49	65	128	0	7.2	7.2	12
	7	23.0	7.3	45.1	8.0	70	-	-	-	-	-	-	-
	8	26.3	7.3	45.1	7.8	68	-	-	-	-	-	-	-
	9	29.5	7.2	45.0	7.5	65	66	65	160	0	7.1	7.2	13
	10	32.8	7.2	45.0	7.4	64	-	-	-	-	-	-	-
	11	36.1	7.2	45.0	7.2	63	-	-	-	-	-	-	-
	12	39.4	7.2	45.0	7.1	62	67	65	161	0	7.0	7.2	15
	12.4	40.7B[4]	7.2	45.0	6.9	60	-	-	-	-	-	-	-
Secchi depth: 0.8 m (2.6 ft)													

APPENDIX 1A. PHYSICAL WATER QUALITY CHARACTERISTICS OF MORRIS RESERVOIR NEAR THE DAM (Continued)

Date	Depth m	Depth ft	Temperature °C	Temperature °F	D.O.[1] (mg/L)	D.O.[1] (% Sat.)	Alkalinity (mg $CaCO_3$/L)	Color (APHA Units)	EC[2] (umhos/cm)	Odor[3]	pH Field	pH Lab	Turbidity (NTU)
03/17/87	0	0.0	10.7	51.3	10.0	95	35	80	90	0	7.0	7.0	15
	1	3.3	8.8	47.8	10.1	91	-	-	-	-	-	-	-
	2	6.6	8.4	47.1	10.1	90	-	-	-	-	-	-	-
	3	9.9	8.1	46.6	9.7	86	40	70	101	0	7.1	7.1	14
	4	13.1	7.9	46.2	8.7	77	-	-	-	-	-	-	-
	5	16.4	7.9	46.2	7.8	69	-	-	-	-	-	-	-
	6	19.7	7.7	45.9	7.7	68	60	65	146	0	7.0	7.1	11
	7	23.0	7.7	45.9	7.4	65	-	-	-	-	-	-	-
	8	26.3	7.7	45.9	7.2	63	-	-	-	-	-	-	-
	9	29.5	7.7	45.9	7.1	63	61	65	148	0	7.0	7.0	11
	10	32.8	7.6	44.6	7.0	61	-	-	-	-	-	-	-
	11	36.1	7.6	44.6	6.7	59	-	-	-	-	-	-	-
	12	39.4	7.6	44.6	6.4	56	62	65	151	0	7.0	7.0	12
	13	42.7	7.7	45.9	5.7	50	-	-	-	-	-	-	-
	13.2	43.3B[4]	7.7	45.9	4.7	41	-	-	-	-	-	-	-
	Secchi depth: 0.6 m (2.0 ft)												
04/02/87	0	0.0	12.9	55.2	9.4	93	47	45	123	0	7.2	7.2	6.7
	1	3.3	11.8	53.2	10.2	99	-	-	-	-	-	-	-
	2	6.6	10.3	50.5	10.3	97	-	-	-	-	-	-	-
	3	9.9	9.3	48.7	10.2	93	48	45	127	0	7.1	7.2	7.4
	4	13.1	8.3	46.9	9.5	85	-	-	-	-	-	-	-
	5	16.4	7.9	46.2	9.1	81	-	-	-	-	-	-	-
	6	19.7	7.8	46.0	8.5	75	53	45	133	0	7.0	7.1	7.8
	7	23.0	7.7	45.9	8.2	72	-	-	-	-	-	-	-
	8	26.3	7.7	45.9	8.2	72	-	-	-	-	-	-	-
	9	29.5	7.6	45.7	8.3	73	58	50	142	0	7.0	7.2	8.2
	10	32.8	7.6	45.7	8.3	73	-	-	-	-	-	-	-
	11	36.1	7.6	45.7	8.3	73	-	-	-	-	-	-	-
	12	39.4	7.6	45.7	8.3	73	57	50	143	0	7.0	7.1	9.0
	13	42.7	7.6	45.7	7.8	68	58	55	143	0	7.0	7.1	14.0
	13.1	43.0B[4]	7.6	45.7	7.8	68	-	-	-	-	-	-	-
	Secchi depth: 1.5 m (5.0 ft)												

APPENDIX 1A. PHYSICAL WATER QUALITY CHARACTERISTICS OF MORRIS RESERVOIR NEAR THE DAM (Continued)

Date	Depth m	Depth ft	Temperature °C	Temperature °F	D.O.[1] (mg/L)	D.O.[1] (% Sat.)	Alkalinity (mg $CaCO_3$/L)	Color (APHA Units)	EC[2] (umhos/cm)	Odor[3]	pH Field	pH Lab	Turbidity (NTU)
04/13/87	0	0.0	17.9	64.2	9.0	99	52	35	120	0	7.3	7.2	2.8
	1	3.3	16.2	61.2	9.2	98	-	-	-	-	-	-	-
	2	6.6	11.4	52.5	10.3	99	-	-	-	-	-	-	-
	3	9.9	9.8	49.6	10.0	93	52	40	121	0	7.1	7.2	6.1
	4	13.1	8.8	47.8	9.3	84	-	-	-	-	-	-	-
	5	16.4	8.2	46.8	8.6	77	-	-	-	-	-	-	-
	6	19.7	7.8	46.0	8.3	74	55	55	128	0	7.1	7.1	8.5
	7	23.0	7.8	46.0	7.7	68	-	-	-	-	-	-	-
	8	26.3	7.7	45.9	7.7	68	-	-	-	-	-	-	-
	9	29.5	7.7	45.9	7.7	68	56	50	132	0	7.0	7.1	8.7
	10	32.8	7.7	45.9	7.8	69	-	-	-	-	-	-	-
	11	36.1	7.7	45.9	7.5	66	57	50	134	0	7.0	7.1	9.3
	12	39.4	7.7	45.9	5.6	49	-	-	-	-	-	-	-
	12.5	41.0B[4]	7.7	45.9	4.2	37	63	70	150	0	7.0	7.0	13.0
	Secchi depth: 1.8 m (6.1 ft)												
05/07/87	0	0.0	23.2	73.8	8.9	109	65	25	169	0	7.6	7.6	0.8
	1	3.3	21.1	70.0	9.6	113	-	-	-	-	-	-	-
	2	6.6	19.5	67.1	9.9	113	-	-	-	-	-	-	-
	3	9.9	15.7	60.3	11.1	117	74	25	186	0	7.4	7.4	1.0
	4	13.1	12.8	55.0	10.9	108	-	-	-	-	-	-	-
	5	16.4	9.9	49.2	7.8	72	-	-	-	-	-	-	-
	6	19.7	8.5	47.3	6.4	57	56	35	149	0	7.0	7.1	5.3
	7	23.0	8.2	46.8	5.7	51	-	-	-	-	-	-	-
	8	26.3	8.1	46.6	5.2	46	-	-	-	-	-	-	-
	9	29.5	8.0	46.4	5.6	50	57	45	151	0	6.9	7.1	7.1
	10	32.8	8.0	46.4	5.7	51	-	-	-	-	-	-	-
	11	36.1	8.0	46.4	5.7	51	-	-	-	-	-	-	-
	12	39.4	8.0	46.4	4.2	37	57	50	150	0	6.9	7.1	7.4
	13	42.7B[4]	8.0	46.4	0.8	7	-	-	-	-	-	-	-
	Secchi depth: 2.7 m (8.8 ft)												

APPENDIX 1A. PHYSICAL WATER QUALITY CHARACTERISTICS OF MORRIS RESERVOIR NEAR THE DAM (Continued)

Date	Depth m	Depth ft	Temperature °C	Temperature °F	D.O.[1] (mg/L)	D.O.[1] (% Sat.)	Alkalinity (mg $CaCO_3$/L)	Color (APHA Units)	EC[2] (umhos/cm)	Odor[3]	pH Field	pH Lab	Turbidity (NTU)
05/18/87	0	0.0	22.6	72.7	8.1	98	-	-	-	-	-	-	-
	1	3.3	22.5	72.5	8.0	97	-	-	-	-	-	-	-
	2	6.6	21.9	71.4	8.0	96	-	-	-	-	-	-	-
	3	9.9	19.3	66.7	11.2	127	-	-	-	-	-	-	-
	4	13.1	16.5	61.7	11.9	128	-	-	-	-	-	-	-
	5	16.4	13.0	55.4	9.6	96	-	-	-	-	-	-	-
	6	19.7	10.1	50.2	6.6	62	-	-	-	-	-	-	-
	7	23.0	8.8	47.8	5.1	46	-	-	-	-	-	-	-
	8	26.3	8.4	47.1	4.8	43	-	-	-	-	-	-	-
	9	29.5	8.3	46.9	4.3	38	-	-	-	-	-	-	-
	10	32.8	8.2	46.8	4.2	37	-	-	-	-	-	-	-
	11	36.1	8.2	46.8	4.0	36	-	-	-	-	-	-	-
	12	39.4	8.2	46.8	1.6	14	-	-	-	-	-	-	-
	13	42.7B[4]	8.2	46.8	0.4	4	-	-	-	-	-	-	-
Secchi depth: -													
06/05/87	0	0.0	21.8	71.2	8.1	97	79	20	196	0	7.4	7.8	0.4
	1	3.3	21.7	71.1	8.2	98	-	-	-	-	-	-	-
	2	6.6	21.6	70.1	8.3	99	-	-	-	-	-	-	-
	3	9.9	20.6	69.1	8.6	100	81	20	200	0	7.3	7.6	0.4
	4	13.1	19.6	67.3	8.7	99	-	-	-	-	-	-	-
	5	16.4	17.3	63.1	11.7	128	-	-	-	-	-	-	-
	6	19.7	13.3	55.9	8.2	82	61	25	161	0	7.0	7.3	1.1
	7	23.0	11.1	52.0	4.8	46	-	-	-	-	-	-	-
	8	26.3	9.9	49.8	3.1	29	-	-	-	-	-	-	-
	9	29.5	9.4	48.9	2.4	22	59	25	152	0	6.8	7.1	1.2
	10	32.8	9.2	48.6	1.9	17	-	-	-	-	-	-	-
	11	36.1	9.1	48.4	1.0	9	-	-	-	-	-	-	-
	12	39.4	8.9	48.0	0.6	5	64	35	164	0	6.8	7.1	3.0
	12.5	41.0B[4]	8.8	47.8	0.1	1	-	-	-	-	-	-	-
Secchi depth: 5.2 m (16.8 ft)													

PPENDIX 1A. PHYSICAL WATER QUALITY CHARACTERISTICS OF MORRIS RESERVOIR NEAR THE DAM (Continued)

Date	Depth m	Depth ft	Temperature °C	Temperature °F	D.O.[1] (mg/L)	D.O.[1] (% Sat.)	Alkalinity (mg $CaCO_3$/L)	Color (APHA Units)	EC[2] (umhos/cm)	Odor[3]	pH Field	pH Lab	Turbidity (NTU)
06/11/87	0	0.0	23.6	74.5	8.0	99	-	-	-	-	-	-	-
	1	3.3	23.4	74.1	8.1	99	-	-	-	-	-	-	-
	2	6.6	23.3	73.9	8.1	99	-	-	-	-	-	-	-
	3	9.9	22.7	72.9	8.7	105	-	-	-	-	-	-	-
	4	13.1	21.1	70.0	8.4	99	-	-	-	-	-	-	-
	5	16.4	18.6	65.5	10.5	118	-	-	-	-	-	-	-
	6	19.7	15.1	59.0	9.3	97	-	-	-	-	-	-	-
	7	23.0	12.6	54.7	5.5	54	-	-	-	-	-	-	-
	8	26.3	10.9	51.6	2.7	26	-	-	-	-	-	-	-
	9	29.5	10.0	50.0	1.5	14	-	-	-	-	-	-	-
	10	32.8	9.6	49.3	0.6	6	-	-	-	-	-	-	-
	11	36.1	9.5	49.1	0.4	4	-	-	-	-	-	-	-
	11.2	36.7B[4]	9.5	49.1	0.3	3	-	-	-	-	-	-	-
Secchi depth: -													
06/25/87	0	0.0	24.1	75.4	8.9	111	84	10	218	0	7.9	8.0	0.3
	1	3.3	23.6	74.5	9.0	111	-	-	-	-	-	-	-
	2	6.6	23.4	74.1	8.9	109	-	-	-	-	-	-	-
	3	9.9	23.0	73.4	8.9	108	84	15	208	0	7.8	8.0	0.3
	4	13.1	22.5	72.5	8.6	104	-	-	-	-	-	-	-
	5	16.4	21.5	70.7	7.6	90	-	-	-	-	-	-	-
	6	19.7	18.8	65.8	8.2	92	79	25	199	0	7.2	7.6	0.6
	7	23.0	16.5	61.7	7.6	82	-	-	-	-	-	-	-
	8	26.3	14.3	57.7	4.9	50	-	-	-	-	-	-	-
	9	29.5	13.2	55.8	2.9	29	60	25	161	0	6.9	7.4	1.3
	10	32.8	12.3	54.1	0.6	6	-	-	-	-	-	-	-
	11	36.1B[4]	11.2	52.2	0.2	2	65	45	167	0	6.9	7.4	4.4
Secchi depth: 7.9 m (25.5 ft)													

APPENDIX 1B. PHYSICAL WATER QUALITY CHARACTERISTICS OF MORRIS RESERVOIR IN THE DAVIS CREEK ARM

Date	Depth m	Depth ft	Temperature °C	Temperature °F	D.O.[1] (mg/L)	D.O.[1] (% Sat.)	Alkalinity (mg $CaCO_3$/L)	Color (APHA Units)	EC[2] (umhos/cm)	Odor[3]	pH Field	pH Lab	Turbidity (NTU)
04/24/86	0	0.0	16.5	61.7	9.0	97	82	-	181	0	7.4	8.2	0.9
	1	3.3	16.5	61.7	9.0	97	-	-	-	-	-	-	-
	2	6.6	16.5	61.7	8.9	96	-	-	-	-	-	-	-
	3	9.8	15.0	59.0	8.6	89	85	-	186	0	7.3	8.2	1.5
	4	13.1	13.7	56.7	8.8	89	90	-	194	0	7.3	8.2	1.5
	4.5	14.8B[4]	13.2	55.8	8.9	89	-	-	-	-	-	-	-
Secchi depth: 2.6 m (8.6 ft)													
05/21/86	0	0.0	19.8	67.6	8.7	100	95	-	201	0	7.8	8.1	0.5
	1	3.3	19.8	67.6	8.6	99	-	-	-	-	-	-	-
	2	6.6	19.6	67.3	8.4	96	-	-	-	-	-	-	-
	3	9.8	17.9	64.2	8.2	91	-	-	-	-	-	-	-
	4	13.1B[4]	16.9	62.4	7.6	82	-	-	-	-	-	-	-
Secchi depth: 2.9 m (9.5 ft)													
06/05/86	0	0.0	22.3	72.1	8.1	97	98	-	203	0	7.5	7.9	0.6
	1	3.3	22.3	72.1	8.1	97	-	-	-	-	-	-	-
	2	6.6	22.3	72.1	8.1	97	-	-	-	-	-	-	-
	3	9.8	21.7	71.1	6.7	80	101	-	209	0	7.2	7.6	1.1
	4	13.1B[4]	20.6	69.1	6.5	76	-	-	-	-	-	-	-
Secchi depth: 2.4 m (7.9 ft)													

1/ Dissolved oxygen in milligrams per liter (mg/L) or percent saturation (% Sat.)
2/ Electrical conductivity
3/ (0) none detected, (+) slight odor, (++) strong odor
4/ Bottom

APPENDIX 1B. PHYSICAL WATER QUALITY CHARACTERISTICS OF MORRIS RESERVOIR IN THE DAVIS CREEK ARM

Date	Depth m	Depth ft	Temperature °C	Temperature °F	D.O.[1] (mg/L)	D.O.[1] (% Sat.)	Alkalinity (mg $CaCO_3$/L)	Color (APHA Units)	EC[2] (umhos/cm)	Odor[3]	pH Field	pH Lab	Turbidity (NTU)
06/18/86	0	0.0	22.4	72.3	9.5	115	104	-	222	0	7.9	8.0	1.0
	1	3.3	22.3	72.1	9.6	115	-	-	-	-	-	-	-
	2	6.6	22.2	72.0	9.6	115	105	-	223	0	8.0	8.1	1.4
	3	9.8	22.1	71.8	9.6	115	-	-	-	-	-	-	-
	3.5	11.5	-	-	-	-	105	-	225	0	7.7	7.9	4.6
	4	13.1B[4]	21.5	70.7	8.7	-	-	-	-	-	-	-	-
Secchi depth: 2.1 m (6.9 ft)													
07/09/86	0	0.0	24.6	76.3	8.0	100	106	-	238	0	7.7	7.8	0.8
	1	3.3	24.3	75.7	7.2	90	-	-	-	-	-	-	-
	2	6.6	24.1	75.4	6.8	85	-	-	-	-	-	-	-
	3	9.8B[4]	23.7	74.7	6.8	84	110	-	241	0	7.4	7.8	4.2
Secchi depth: 2.6 m (8.5 ft)													
07/24/86	0	0.0	25.3	77.5	7.7	98	113	-	245	0	7.5	7.8	0.9
	1	3.3	24.8	76.6	7.7	97	-	-	-	-	-	-	-
	2	6.6	24.6	76.3	7.8	98	-	-	-	-	-	-	-
	3	9.8	24.3	75.7	7.8	97	118	-	253	0	7.4	7.8	1.3
	4	13.1	24.1	75.4	7.8	97	-	-	-	-	-	-	-
	4.5	14.8B[4]	23.8	74.8	7.8	96	-	-	-	-	-	-	-
Secchi depth: 3.0 m (9.8 ft)													
08/07/86	0	0.0	25.8	78.4	7.6	97	114	-	261	0	7.8	7.8	1.2
	1	3.3	25.6	78.1	7.6	97	-	-	-	-	-	-	-
	2	6.6	25.5	77.9	7.5	96	114	-	255	0	7.7	7.8	1.2
	2.5	8.2B[4]	25.2	77.4	7.3	93	-	-	-	-	-	-	-
Secchi depth: 1.7 m (5.6 ft)													

APPENDIX 1B. PHYSICAL WATER QUALITY CHARACTERISTICS OF MORRIS RESERVOIR IN THE DAVIS CREEK ARM

Date	Depth m	Depth ft	Temperature °C	Temperature °F	D.O.[1] (mg/L)	D.O.[1] (% Sat.)	Alkalinity (mg $CaCO_3$/L)	Color (APHA Units)	EC[2] (umhos/cm)	Odor[3]	pH Field	pH Lab	Turbidity (NTU)
08/21/86	0	0.0	26.2	79.2	7.9	102	118	10	268	0	7.7	7.8	1.3
	1	3.3	25.4	77.7	7.8	99	-	-	-	-	-	-	-
	2	6.6	24.5	76.1	7.9	99	-	-	-	-	-	-	-
	3	9.8	24.1	75.4	7.7	96	118	10	270	0	7.6	7.8	2.0
	3.5	11.5B[4]	24.0	75.2	7.1	88	-	-	-	-	-	-	-
	Secchi depth: 2.2 m (7.2 ft)												
09/11/86	0	0.0	22.9	73.2	10.0	122	130	20	263	0	8.0	7.9	1.5
	1	3.3	22.0	71.6	9.5	114	-	-	-	-	-	-	-
	2	6.6	21.9	71.4	8.8	105	-	-	-	-	-	-	-
	2.5	8.2	-	-	-	-	131	20	278	0	7.7	7.6	3.0
	3	9.8	21.8	71.2	8.6	102	-	-	-	-	-	-	-
	3.1	10.2B[4]	21.7	71.1	7.9	94	-	-	-	-	-	-	-
	Secchi depth: -												
09/25/86	0	0.0	17.4	63.3	7.5	82	125	-	283	0	7.5	7.7	2.1
	1	3.3	17.3	63.1	7.5	82	-	-	-	-	-	-	-
	2	6.6	17.3	63.1	7.3	80	-	-	-	-	-	-	-
	2.4	7.9	-	-	-	-	123	-	283	0	7.3	7.7	8.3
	2.7	8.9B[4]	16.4	61.5	8.0	86	-	-	-	-	-	-	-
	Secchi depth: 1.8 m (6.1 ft)												
10/10/86	0	0.0	19.2	66.5	9.6	109	127	15	291	0	7.7	7.9	2.2
	1	3.3	-	-	-	-	-	-	-	-	-	-	-
	2	6.6B[4]	-	-	-	-	127	15	294	0	7.7	7.9	3.3
	Secchi depth: 1.6 m (5.2 ft)												

APPENDIX 1B. PHYSICAL WATER QUALITY CHARACTERISTICS OF MORRIS RESERVOIR IN THE DAVIS CREEK ARM

Date	Depth m	Depth ft	Temperature °C	Temperature °F	D.O.[1] (mg/L)	D.O.[1] (% Sat.)	Alkalinity (mg $CaCO_3$/L)	Color (APHA Units)	EC[2] (umhos/cm)	Odor[3]	pH Field	pH Lab	Turbidity (NTU)
10/24/86	0	0.0	15.1	59.2	9.6	100	134	20	285	0	7.9	8.1	2.8
	1	3.3	15.1	59.2	9.6	100	-	-	-	-	-	-	-
	2	6.6	15.1	59.2	9.5	99	133	20	281	0	7.9	8.1	2.7
	3	9.8	15.1	59.2	9.5	99	-	-	-	-	-	-	-
	3.5	11.5	-	-	-	-	134	20	285	0	7.9	8.1	2.8
	4	13.1	15.1	59.2	9.4	98	-	-	-	-	-	-	-
	4.8	15.7B[4]	14.7	58.5	9.0	93	-	-	-	-	-	-	-
Secchi depth: 0.8 m (2.6 ft)													
11/06/86	0	0.0	14.6	58.3	7.9	81	137	-	295	0	7.3	8.0	2.6
	1	3.3	14.1	57.4	7.8	80	-	-	-	-	-	-	-
	2	6.6	13.8	56.8	7.8	79	-	-	-	-	-	-	-
	2.5	8.2	-	-	-	-	138	-	295	0	7.4	7.9	4.8
	3	9.8B[4]	13.6	56.5	7.7	78	-	-	-	-	-	-	-
Secchi depth: 0.7 m (2.3 ft)													
11/21/86	0	0.0	11.8	53.2	9.2	89	139	-	291	0	7.4	7.8	3.0
	1	3.3	11.6	52.9	9.0	87	-	-	-	-	-	-	-
	2	6.6	11.3	52.3	8.6	82	-	-	-	-	-	-	-
	2.5	8.2	-	-	-	-	138	-	301	0	7.4	7.8	3.8
	2.8	9.2B[4]	11.3	52.3	8.6	82	-	-	-	-	-	-	-
Secchi depth: 0.7 m (2.3 ft)													
12/11/86	0	0.0	8.4	47.1	9.9	89	142	20	307	0	7.3	7.8	2.6
	1	3.3	8.0	46.4	9.9	88	-	-	-	-	-	-	-
	2	6.6	7.8	46.0	9.9	87	141	20	307	0	7.4	7.8	2.9
	3	9.8	7.8	46.0	9.9	87	-	-	-	-	-	-	-
	4	13.1B[4]	7.6	45.7	9.7	85	143	25	310	0	7.3	7.8	3.3
Secchi depth: 1.1 m (3.6 ft)													

APPENDIX 1B. PHYSICAL WATER QUALITY CHARACTERISTICS OF MORRIS RESERVOIR IN THE DAVIS CREEK ARM

Date	Depth m	Depth ft	Temperature °C	Temperature °F	D.O.[1] (mg/L)	D.O.[1] (% Sat.)	Alkalinity (mg $CaCO_3$/L)	Color (APHA Units)	EC[2] (umhos/cm)	Odor[3]	pH Field	pH Lab	Turbidity (NTU)
12/23/86	0	0.0	7.9	46.2	10.3	91	133	30	285	0	7.3	7.8	5.1
	1	3.3	7.8	46.0	10.3	91	-	-	-	-	-	-	-
	2	6.6	7.5	45.5	10.1	88	134	25	296	0	7.3	7.8	4.8
	3	9.8	7.4	45.3	9.3	81	-	-	-	-	-	-	-
	3.5	11.5B[4]	7.3	45.1	9.2	80	133	30	292	0	7.3	7.7	6.7
Secchi depth: 0.8 m (2.6 ft)													
01/09/87	0	0.0	7.0	44.6	9.5	82	78	55	193	0	7.2	7.2	14
	1	3.3	7.0	44.6	9.5	82	-	-	-	-	-	-	-
	2	6.6	7.0	44.6	9.5	82	81	60	198	0	7.1	7.3	32
	2.5	8.2B[4]	6.5	43.7	9.6	82	-	-	-	-	-	-	-
Secchi depth: 0.4 m (1.3 ft)													
01/22/87	0	0.0	5.8	42.4	9.8	82	78	55	198	0	7.3	7.3	8.4
	1	3.3	5.8	42.4	9.8	82	-	-	-	-	-	-	-
	2	6.6	5.8	42.4	9.7	81	78	55	197	0	7.3	7.3	8.5
	2.5	8.2B[4]	5.0	41.0	10.3	85	-	-	-	-	-	-	-
Secchi depth: 1.0 m (3.3 ft)													
02/05/87	0	0.0	12.1	53.8	10.8	105	40	65	107	0	7.2	7.0	16
	1	3.3	8.7	47.7	10.9	98	-	-	-	-	-	-	-
	2	6.6	7.6	45.7	10.7	94	-	-	-	-	-	-	-
	3	9.8	7.1	44.8	10.5	91	66	55	156	0	7.2	7.3	10
	3.1	10.2B[4]	7.1	44.8	10.5	91	-	-	-	-	-	-	-
Secchi depth: 0.5 m (1.6 ft)													

APPENDIX 1B. PHYSICAL WATER QUALITY CHARACTERISTICS OF MORRIS RESERVOIR IN THE DAVIS CREEK ARM

Date	Depth m	Depth ft	Temperature °C	Temperature °F	D.O.[1] (mg/L)	D.O.[1] (% Sat.)	Alkalinity (mg $CaCO_3$/L)	Color (APHA Units)	EC[2] (umhos/cm)	Odor[3]	pH Field	pH Lab	Turbidity (NTU)
02/18/87	0	0.0	9.8	49.6	10.3	95	40	100	100	0	7.2	7.2	21
	1	3.3	9.2	48.6	10.4	95	-	-	-	-	-	-	-
	2	6.6	8.5	47.3	10.3	92	-	-	-	-	-	-	-
	3	9.8	7.8	46.0	10.7	94	54	90	133	0	7.2	7.3	13
	3.3	10.8B[4]	7.8	46.0	10.6	94	-	-	-	-	-	-	-
Secchi depth: 0.4 m (1.3 ft)													
03/04/87	0	0.0	8.7	47.7	9.9	89	56	55	140	0	7.2	7.1	11
	1	3.3	8.6	47.5	9.9	89	-	-	-	-	-	-	-
	2	6.6	8.6	47.5	9.9	89	-	-	-	-	-	-	-
	3	9.8B[4]	8.5	47.3	9.9	89	61	55	149	0	7.2	7.3	10
Secchi depth: 0.8 m (2.6 ft)													
03/17/87	0	0.0	12.5	54.5	10.0	99	35	70	89	0	7.3	7.0	16
	1	3.3	10.5	50.9	10.0	94	-	-	-	-	-	-	-
	2	6.6	10.0	50.0	8.7	81	-	-	-	-	-	-	-
	3	9.8	10.1	50.2	8.3	77	54	50	129	0	7.2	7.1	9.3
	3.5	11.5B[4]	10.0	50.0	8.1	75	-	-	-	-	-	-	-
Secchi depth: 0.6 m (2.0 ft)													
04/03/87	0	0.0	13.4	56.1	9.5	95	45	45	121	0	7.2	7.2	5.8
	1	3.3	12.7	54.9	9.3	92	-	-	-	-	-	-	-
	2	6.6	9.7	49.5	9.3	86	-	-	-	-	-	-	-
	3	9.8	8.4	47.1	9.3	83	56	45	140	0	7.1	7.1	6.5
	4	13.1B[4]	7.8	46.0	8.6	76	-	-	-	-	-	-	-
Secchi depth: 1.1 m (3.7 ft)													

APPENDIX 1B. PHYSICAL WATER QUALITY CHARACTERISTICS OF MORRIS RESERVOIR IN THE DAVIS CREEK ARM

Date	Depth m	Depth ft	Temperature °C	Temperature °F	D.O.[1] (mg/L)	D.O.[1] (% Sat.)	Alkalinity (mg $CaCO_3$/L)	Color (APHA Units)	EC[2] (umhos/cm)	Odor[3]	pH Field	pH Lab	Turbidity (NTU)
04/13/87	0	0.0	17.0	62.6	8.6	93	53	30	126	0	7.3	7.2	2.6
	1	3.3	15.2	59.4	8.1	85	-	-	-	-	-	-	-
	2	6.6	13.4	56.1	8.8	88	69	25	160	0	7.3	7.2	3.2
	3	9.8	10.5	50.9	9.2	87	-	-	-	-	-	-	-
	3.5	11.5B[4]	9.5	49.1	8.4	77	-	-	-	-	-	-	-
Secchi depth: 1.9 m (6.2 ft)													
05/07/87	0	0.0	24.5	76.1	8.5	106	65	15	169	0	7.6	7.4	0.6
	1	3.3	21.0	69.8	8.3	97	-	-	-	-	-	-	-
	2	6.6	19.0	66.2	9.8	111	-	-	-	-	-	-	-
	3	9.8	16.6	61.9	9.6	103	83	15	205	0	7.4	7.5	1.0
	3.5	11.5B[4]	14.3	57.7	10.5	108	-	-	-	-	-	-	-
Secchi depth: 2.3 m (7.6 ft)													
06/05/87	0	0.0	21.7	71.1	8.3	99	80	20	196	0	7.4	7.8	0.4
	1	3.3	21.7	71.1	8.4	100	-	-	-	-	-	-	-
	2	6.6	21.7	71.1	8.4	100	-	-	-	-	-	-	-
	3	9.8B[4]	21.3	70.3	8.5	100	83	20	203	0	7.3	7.6	0.6
Secchi depth: 3.3 m (10.7 ft)													
06/25/87	0	0.0	24.0	75.2	9.3	115	85	10	208	0	7.9	8.1	0.3
	1	3.3	23.5	74.3	9.4	116	-	-	-	-	-	-	-
	2	6.6	23.4	74.1	9.5	117	-	-	-	-	-	-	-
	3	9.8B[4]	23.0	73.4	9.3	113	85	15	206	0	7.9	8.1	0.5
Secchi depth: 3.0 m (9.8 ft)													

APPENDIX 1C. PHYSICAL WATER QUALITY CHARACTERISTICS OF MORRIS RESERVOIR IN THE EAST TRIBUTARY ARM

Date	Depth m	Depth ft	Temperature °C	Temperature °F	D.O.[1] (mg/L)	D.O.[1] (% Sat.)	Alkalinity (mg $CaCO_3$/L)	Color (APHA Units)	EC[2] (umhos/cm)	Odor[3]	pH Field	pH Lab	Turbidity (NTU)
04/24/86	0	0.0	16.7	62.1	8.9	96	82	-	178	0	7.3	8.2	1.0
	1	3.3	16.5	61.7	8.9	96	-	-	-	-	-	-	-
	2	6.6	16.2	61.2	8.9	95	81	-	178	0	7.3	8.2	1.0
	3	9.8	15.8	60.4	8.8	93	-	-	-	-	-	-	-
	4	13.1	13.7	56.7	8.9	90	88	-	194	0	7.3	8.3	1.3
	5	16.4	12.2	54.0	7.5	73	-	-	-	-	-	-	-
	6	19.7	10.8	51.4	5.5	52	64	-	148	0	7.0	7.8	2.1
	7	23.0	9.2	48.6	3.3	30	-	-	-	-	-	-	-
	7.8	25.6B[4]	9.0	48.2	2.9	26	-	-	-	-	-	-	-
	Secchi depth: 3.1 m (10 ft)												
05/21/86	0	0.0	19.9	67.8	8.9	102	94	-	200	0	7.8	8.1	0.6
	1	3.3	19.8	67.6	8.9	102	-	-	-	-	-	-	-
	2	6.6	19.6	67.3	8.9	102	-	-	-	-	-	-	-
	3	9.8	17.8	64.0	8.8	97	-	-	-	-	-	-	-
	4	13.1	16.7	62.1	11.8	119	-	-	-	-	-	-	-
	5	16.4	15.6	60.1	9.5	100	-	-	-	-	-	-	-
	6	19.7	13.2	55.8	4.3	43	-	-	-	-	-	-	-
	7	23.0	11.6	52.9	0.5	5	-	-	-	-	-	-	-
	7.5	24.7B[4]	10.8	51.4	0	0	-	-	-	-	-	-	-
	Secchi depth: 3.4 m (11.2 ft)												

1/ Dissolved oxygen in milligrams per liter (mg/L) or percent saturation (% Sat.)
2/ Electrical conductivity
3/ (0) none detected, (+) slight odor, (++) strong odor
4/ Bottom

APPENDIX 1C. PHYSICAL WATER QUALITY CHARACTERISTICS OF MORRIS RESERVOIR IN THE EAST TRIBUTARY ARM

Date	Depth m	Depth ft	Temperature °C	Temperature °F	D.O.[1] (mg/L)	D.O.[1] (% Sat.)	Alkalinity (mg $CaCO_3$/L)	Color (APHA Units)	EC[2] (umhos/cm)	Odor[3]	pH Field	pH Lab	Turbidity (NTU)
06/05/86	0	0.0	22.3	72.1	8.3	100	97	-	209	0	7.5	7.8	0.5
	1	3.3	22.3	72.1	8.4	101	-	-	-	-	-	-	-
	2	6.6	22.3	72.1	8.4	101	-	-	-	-	-	-	-
	3	9.8	21.4	70.5	7.4	88	99	-	203	0	7.2	7.7	1.3
	4	13.1	20.0	68.0	12.5	144	-	-	-	-	-	-	-
	5	16.4	17.7	63.9	9.9	109	-	-	-	-	-	-	-
	6	19.7	14.9	58.8	4.9	51	93	-	198	0	7.0	7.5	2.4
	7	23.0B[4]	13.0	55.4	0.3	3	-	-	-	-	-	-	-
Secchi depth: 2.5 m (8.2 ft)													
06/18/86	0	0.0	22.5	72.5	9.8	118	104	-	223	0	8.0	8.1	1.2
	1	3.3	22.3	72.1	9.9	119	-	-	-	-	-	-	-
	2	6.6	22.2	72.0	10.0	120	-	-	-	-	-	-	-
	3	9.8	22.0	71.6	10.1	121	103	-	220	0	7.9	8.0	1.3
	4	13.1	20.2	68.4	7.2	83	-	-	-	-	-	-	-
	5	16.4	18.2	64.8	7.5	83	105	-	224	0	7.2	7.4	0.8
	6	19.7	16.3	61.3	2.0	21	-	-	-	-	-	-	-
	7	23.0	14.9	58.8	0.0	0	93	-	204	0	7.0	7.1	7.6
	7.5	24.7B[4]	14.7	58.5	0.0	0	-	-	-	-	-	-	-
Secchi depth: 2.1 m (6.9 ft)													
07/09/86	0	0.0	24.6	76.3	8.0	100	107	-	238	0	7.6	7.8	0.8
	1	3.3	24.2	75.6	7.9	98	-	-	-	-	-	-	-
	2	6.6	24.1	75.4	7.6	95	-	-	-	-	-	-	-
	3	9.8	23.9	75.0	7.4	92	106	-	237	0	7.6	7.8	1.0
	4	13.1	23.6	74.5	7.0	86	-	-	-	-	-	-	-
	5	16.4	22.1	71.8	7.2	86	-	-	-	-	-	-	-
	6	19.7	18.8	65.8	0.0	0	106	-	234	0	7.0	7.1	3.2
	7	23.0B[4]	17.0	62.6	0.0	0	-	-	-	-	-	-	-
Secchi depth: 2.6 m (8.5 ft)													

APPENDIX 1C. PHYSICAL WATER QUALITY CHARACTERISTICS OF MORRIS RESERVOIR IN THE EAST TRIBUTARY ARM

Date	Depth m	Depth ft	Temperature °C	Temperature °F	D.O.[1] (mg/L)	D.O.[1] (% Sat.)	Alkalinity (mg $CaCO_3$/L)	Color (APHA Units)	EC[2] (umhos/cm)	Odor[3]	pH Field	pH Lab	Turbidity (NTU)
07/24/86	0	0.0	25.3	77.5	7.6	97	111	-	246	0	7.6	7.8	1.0
	1	3.3	24.9	76.8	7.6	96	-	-	-	-	-	-	-
	2	6.6	24.7	76.5	7.5	94	-	-	-	-	-	-	-
	3	9.8	24.4	75.9	7.3	91	108	-	246	0	-	7.8	1.4
	4	13.1	24.2	75.6	7.1	88	-	-	-	-	-	-	-
	5	16.4	23.2	73.8	7.6	93	112	-	254	0	7.3	7.5	2.2
	6	19.7	21.3	70.3	4.8	57	-	-	-	-	-	-	-
	6.8	22.3B[4]	18.0	64.4	0.0	0	-	-	-	-	-	-	-
Secchi depth: 2.8 m (9.2 ft)													
08/07/86	0	0.0	25.9	78.6	7.3	94	111	-	259	0	7.6	7.8	1.6
	1	3.3	25.6	78.1	7.1	91	-	-	-	-	-	-	-
	2	6.6	25.4	77.7	7.0	89	-	-	-	-	-	-	-
	3	9.8	25.3	77.5	6.8	86	-	-	-	-	-	-	-
	4	13.1	24.9	76.8	6.6	83	111	-	260	0	7.7	7.7	1.6
	4.8	15.7B[4]	24.2	75.6	5.6	70	-	-	-	-	-	-	-
Secchi depth: 1.6 m (5.2 ft)													
08/21/86	0	0.0	26.0	78.8	7.6	98	116	10	259	0	7.6	7.8	1.4
	1	3.3	25.8	78.4	7.5	96	-	-	-	-	-	-	-
	2	6.6	24.3	75.7	7.5	94	-	-	-	-	-	-	-
	3	9.8	24.2	75.6	7.4	92	116	10	268	0	7.5	7.8	1.7
	4	13.1	24.0	75.2	7.3	91	-	-	-	-	-	-	-
	4.5	14.8B[4]	23.7	74.7	6.7	83	116	15	271	0	7.5	7.8	7.5
Secchi depth: 2.4 m (7.9 ft)													

APPENDIX 1C. PHYSICAL WATER QUALITY CHARACTERISTICS OF MORRIS RESERVOIR IN THE EAST TRIBUTARY ARM

Date	Depth m	Depth ft	Temperature °C	Temperature °F	D.O.[1] (mg/L)	D.O.[1] (% Sat.)	Alkalinity (mg $CaCO_3$/L)	Color (APHA Units)	EC[2] (umhos/cm)	Odor[3]	pH Field	pH Lab	Turbidity (NTU)
09/11/86	0	0.0	23.7	74.7	9.9	122	130	20	277	0	8.0	7.8	2.0
	1	3.3	22.2	72.0	8.8	106	-	-	-	-	-	-	-
	2	6.6	21.9	71.4	7.8	93	-	-	-	-	-	-	-
	3	9.8B[4]	21.8	71.2	7.9	94	129	20	270	0	7.8	7.7	4.0
Secchi depth: 0.9 m (3.0 ft)													
09/25/86	0	0.0	17.7	63.9	7.4	81	123	-	280	0	7.5	7.7	1.4
	1	3.3	17.4	63.3	7.1	78	-	-	-	-	-	-	-
	2	6.6	17.3	63.1	6.9	75	-	-	-	-	-	-	-
	3	9.8	17.2	63.0	6.9	75	123	-	281	0	7.5	7.6	2.2
	3.3	10.8B[4]	17.2	63.0	6.6	72	-	-	-	-	-	-	-
Secchi depth: 1.8 m (6 ft)													
10/10/86	0	0.0	18.6	65.5	9.6	108	130	15	290	0	7.7	7.9	1.8
	1	3.3	18.2	64.8	9.6	107	-	-	-	-	-	-	-
	2	6.6	17.7	63.9	9.4	103	129	15	290	0	7.7	7.8	1.8
	3	9.8	17.1	62.8	4.6	50	-	-	-	-	-	-	-
	4	13.1B[4]	16.7	62.1	3.2	34	129	20	296	0	7.2	7.5	3.6
Secchi depth: 1.5 m (4.9 ft)													
10/24/86	0	0.0	15.1	59.2	10.0	104	134	20	282	0	8.1	8.1	3.2
	1	3.3	15.1	59.2	10.0	104	-	-	-	-	-	-	-
	2	6.6	15.1	59.2	9.8	102	-	-	-	-	-	-	-
	2.2	7.2	-	-	-	-	134	30	284	0	8.0	8.1	10.0
	2.8	9.2B[4]	15.0	59.0	9.4	98	-	-	-	-	-	-	-
Secchi depth: 0.8 m (2.5 ft)													

APPENDIX 1C. PHYSICAL WATER QUALITY CHARACTERISTICS OF MORRIS RESERVOIR IN THE EAST TRIBUTARY ARM

Date	Depth m	Depth ft	Temperature °C	Temperature °F	D.O.[1] (mg/L)	D.O.[1] (% Sat.)	Alkalinity (mg $CaCO_3$/L)	Color (APHA Units)	EC[2] (umhos/cm)	Odor[3]	pH Field	pH Lab	Turbidity (NTU)
11/06/86	0	0.0	14.7	58.5	7.6	79	136	-	290	0	7.3	7.9	2.7
	1	3.3	14.2	57.6	7.2	74	-	-	-	-	-	-	-
	1.5	4.9	-	-	-	-	136	-	290	0	7.3	8.0	2.4
	2	6.6B[4]	13.9	57.0	7.0	71	-	-	-	-	-	-	-
Secchi depth: 0.7 m (2.3 ft)													
11/21/86	0	0.0	11.6	52.9	9.1	88	137	-	294	0	7.4	7.8	2.9
	1	3.3	11.4	57.5	9.3	89	-	-	-	-	-	-	-
	2	6.6	11.2	52.2	8.9	85	140	-	297	0	7.3	7.7	3.7
	2.4	7.9B[4]	11.2	52.2	8.4	80	-	-	-	-	-	-	-
Secchi depth: 0.7 m (2.3 ft)													
12/11/86	0	0.0	8.6	47.5	9.8	88	142	20	311	0	7.3	7.8	2.7
	1	3.3	8.2	46.8	9.8	87	-	-	-	-	-	-	-
	2	6.6	7.9	46.2	9.9	99	142	20	312	0	7.3	7.8	2.9
	3	9.8	7.8	46.0	9.9	87	-	-	-	-	-	-	-
	4	13.1B[4]	7.8	46.0	9.9	87	143	25	315	0	7.3	7.7	3.6
Secchi depth: 0.9 m (3.0 ft)													
12/23/86	0	0.0	7.7	45.9	10.2	90	120	30	270	0	7.3	7.8	7.3
	1	3.3	7.7	45.9	10.2	90	-	-	-	-	-	-	-
	2	6.6	7.6	45.7	10.1	89	130	30	290	0	7.3	7.7	6.2
	3	9.8	7.3	45.1	9.4	82	-	-	-	-	-	-	-
	4	13.1	7.2	45.0	9.1	79	129	35	290	0	7.3	7.7	9.0
	4.5	14.8B[4]	7.2	45.0	9.0	78	-	-	-	-	-	-	-
Secchi depth: 0.7 m (2.5 ft)													

APPENDIX 1C. PHYSICAL WATER QUALITY CHARACTERISTICS OF MORRIS RESERVOIR IN THE EAST TRIBUTARY ARM

Date	Depth m	Depth ft	Temperature °C	Temperature °F	D.O.[1] (mg/L)	D.O.[1] (% Sat.)	Alkalinity (mg $CaCO_3$/L)	Color (APHA Units)	EC[2] (umhos/cm)	Odor[3]	pH Field	pH Lab	Turbidity (NTU)
01/09/87	0	0.0	7.1	44.8	9.6	83	76	55	188	0	7.2	7.2	14
	1	3.3	7.0	44.6	9.6	83	–	–	–	–	–	–	–
	2	6.6	7.0	44.6	9.5	82	76	55	189	0	7.1	7.3	15
	3	9.8	7.0	44.6	9.5	82	–	–	–	–	–	–	–
	4	13.1	6.9	44.4	9.4	81	74	55	185	0	7.1	7.2	16
	5	16.4B[4]	7.0	44.6	9.3	80	75	55	185	0	7.0	7.2	16
Secchi depth: 0.4 m (1.3 ft)													
01/22/86	0	0.0	5.8	42.4	9.7	81	78	55	196	0	7.3	7.3	8.5
	1	3.3	5.7	42.3	9.7	81	–	–	–	–	–	–	–
	2	6.6	5.7	42.3	9.6	80	–	–	–	–	–	–	–
	3	9.8	5.7	42.3	9.6	80	78	55	197	0	7.2	7.2	8.7
	4	13.1	5.6	42.1	9.5	79	77	55	197	0	7.3	7.2	8.6
	4.5	14.8B[4]	5.6	42.1	9.5	79	–	–	–	–	–	–	–
Secchi depth: 1.0 m (3.3 ft)													
02/05/87	0	0.0	12.1	53.8	10.8	105	41	65	107	0	7.2	7.1	16
	1	3.3	9.1	48.4	10.8	98	–	–	–	–	–	–	–
	2	6.6	7.4	45.3	10.7	93	–	–	–	–	–	–	–
	3	9.8	6.9	44.4	10.4	90	44	65	114	0	7.0	7.1	14
	4	13.1	6.8	44.2	9.7	83	–	–	–	–	–	–	–
	5	16.4	6.7	44.1	9.6	82	–	–	–	–	–	–	–
	5.5	18.0B[4]	6.6	43.9	9.3	80	63	65	150	0	7.0	7.2	13
Secchi depth: 0.6 m (2.0 ft)													

APPENDIX 1C. PHYSICAL WATER QUALITY CHARACTERISTICS OF MORRIS RESERVOIR IN THE EAST TRIBUTARY ARM

Date	Depth m	Depth ft	Temperature °C	Temperature °F	D.O.[1] (mg/L)	D.O.[1] (% Sat.)	Alkalinity (mg $CaCO_3$/L)	Color (APHA Units)	EC[2] (umhos/cm)	Odor[3]	pH Field	pH Lab	Turbidity (NTU)
02/18/87	0	0.0	9.8	49.6	10.1	94	39	120	99	0	7.2	7.2	20
	1	3.3	9.1	48.4	10.1	92	-	-	-	-	-	-	-
	2	6.6	9.0	48.2	10.1	92	38	90	96	0	7.2	7.1	21
	3	9.8	8.9	48.0	10.1	92	-	-	-	-	-	-	-
	4	13.1	8.8	47.8	10.2	92	39	100	96	0	7.2	7.2	21
	5	16.4	7.4	45.3	10.1	88	43	90	112	0	7.1	7.1	17
	6	19.7	7.2	45.0	8.6	75	-	-	-	-	-	-	-
	6.7	22.0B[4]	7.2	45.0	8.6	75	-	-	-	-	-	-	-
Secchi depth: 0.4 m (1.1 ft)													
03/04/87	0	0.0	8.2	46.8	9.7	86	48	60	130	0	7.2	7.1	12
	1	3.3	8.1	46.6	9.7	86	-	-	-	-	-	-	-
	2	6.6	8.1	46.6	9.6	85	-	-	-	-	-	-	-
	3	9.8	8.0	46.4	9.5	84	48	55	130	0	7.2	7.1	12
	4	13.1	7.8	46.0	9.2	81	-	-	-	-	-	-	-
	5	16.4	7.5	45.5	8.8	77	-	-	-	-	-	-	-
	5.5	18.0	-	-	-	-	55	65	137	0	7.0	7.2	13
	6	19.7	7.3	45.1	8.2	71	-	-	-	-	-	-	-
	6.5	21.3B[4]	7.3	45.1	8.1	71	-	-	-	-	-	-	-
Secchi depth: 0.8 m (2.6 ft)													
03/17/87	0	0.0	12.9	55.2	10.1	100	35	90	91	0	7.2	7.1	16
	1	3.3	10.3	50.5	10.3	97	-	-	-	-	-	-	-
	2	6.6	8.4	47.1	10.4	93	-	-	-	-	-	-	-
	3	9.8	7.9	46.2	10.4	92	34	90	87	0	7.0	7.0	13
	4	13.1	7.5	45.5	10.5	92	-	-	-	-	-	-	-
	5	16.4	7.4	45.3	10.3	90	34	60	88	0	7.0	7.0	13
	6	19.7B[4]	7.3	45.1	9.8	85	-	-	-	-	-	-	-
Secchi depth: 0.6 m (1.8 ft)													

APPENDIX 1C. PHYSICAL WATER QUALITY CHARACTERISTICS OF MORRIS RESERVOIR IN THE EAST TRIBUTARY ARM

Date	Depth m	Depth ft	Temperature °C	Temperature °F	D.O.[1] (mg/L)	D.O.[1] (% Sat.)	Alkalinity (mg $CaCO_3$/L)	Color (APHA Units)	EC[2] (umhos/cm)	Odor[3]	pH Field	pH Lab	Turbidity (NTU)
04/03/87	0	0.0	13.4	56.1	9.5	95	45	40	120	0	7.2	7.1	6.6
	1	3.3	13.4	56.1	9.5	95	-	-	-	-	-	-	-
	2	6.6	11.4	52.5	8.6	83	-	-	-	-	-	-	-
	3	9.8	9.1	48.4	9.3	85	45	40	120	0	7.0	7.1	6.5
	4	13.1	8.0	46.4	9.2	82	-	-	-	-	-	-	-
	5	16.4	7.8	46.0	8.9	79	-	-	-	-	-	-	-
	6	19.7B[4]	7.7	45.9	8.6	76	50	55	129	0	7.0	7.1	13
Secchi depth: 1.3 m (4.2 ft)													
04/13/87	0	0.0	17.0	62.6	8.8	95	53	35	126	0	7.1	-	2.8
	1	3.3	15.7	60.3	8.8	93	-	-	-	-	-	-	-
	2	6.6	13.7	56.7	8.6	87	-	-	-	-	-	-	-
	3	9.8	11.3	52.3	9.9	95	58	35	135	0	7.1	-	4.1
	4	13.1	9.6	49.3	9.4	87	-	-	-	-	-	-	-
	5	16.4	8.7	47.7	8.4	76	-	-	-	-	-	-	-
	6	19.7B[4]	8.1	46.6	7.6	68	53	45	125	0	7.0	-	8.3
Secchi depth: 2.4 m (7.8 ft)													
05/07/87	0	0.0	25.0	77.0	8.3	105	65	15	170	0	7.6	7.4	0.6
	1	3.3	21.2	70.2	8.1	95	-	-	-	-	-	-	-
	2	6.6	18.2	64.8	9.7	108	-	-	-	-	-	-	-
	3	9.8	16.6	61.9	10.1	109	71	15	180	0	7.3	7.3	0.8
	4	13.1	13.7	56.7	10.1	102	-	-	-	-	-	-	-
	5	16.4	10.6	51.1	7.0	66	-	-	-	-	-	-	-
	6	19.7	8.8	47.8	4.8	43	56	30	150	0	7.0	7.0	4.0
	6.3	19.7B[4]	8.5	47.3	4.1	37	-	-	-	-	-	-	-
Secchi depth: 2.3 m (7.6 ft)													

APPENDIX 1C. PHYSICAL WATER QUALITY CHARACTERISTICS OF MORRIS RESERVOIR IN THE EAST TRIBUTARY ARM

Date	Depth m	Depth ft	Temperature °C	Temperature °F	D.O.[1] (mg/L)	D.O.[1] (% Sat.)	Alkalinity (mg $CaCO_3$/L)	Color (APHA Units)	EC[2] (umhos/cm)	Odor[3]	pH Field	pH Lab	Turbidity (NTU)
06/05/87	0	0.0	21.9	71.4	8.5	101	79	20	197	0	7.3	7.8	0.4
	1	3.3	21.8	71.2	8.6	102	-	-	-	-	-	-	-
	2	6.6	21.8	71.2	8.6	102	-	-	-	-	-	-	-
	3	9.8	20.9	69.6	8.9	104	79	20	196	0	7.3	7.8	0.5
	4	13.1	19.6	67.3	10.1	115	-	-	-	-	-	-	-
	5	16.4	16.7	62.1	11.8	127	-	-	-	-	-	-	-
	5.5	18.0B[4]	15.0	59.0	9.6	100	63	30	163	0	7.0	7.2	2.5
Secchi depth: 5.2 m (16.8 ft)													
06/25/87	0	0.0	23.8	74.8	9.7	120	84	10	205	0	7.9	8.3	0.3
	1	3.3	23.5	74.3	9.6	118	-	-	-	-	-	-	-
	2	6.6	23.3	73.9	10.1	124	-	-	-	-	-	-	-
	3	9.8	23.2	73.8	10.0	122	85	15	208	0	7.9	8.2	0.5
	4	13.1	22.7	72.9	9.9	120	-	-	-	-	-	-	-
	5	16.4	21.3	70.3	9.1	107	-	-	-	-	-	-	-
	5.5	18.0B[4]	19.6	67.3	6.7	77	84	20	206	0	7.1	7.4	1.3
Secchi depth: 5.2 m (17 ft)													

APPENDIX 1D. PHYSICAL WATER QUALITY CHARACTERISTICS OF DAVIS CREEK NEAR THE CONFLUENCE WITH MORRIS RESERVOIR

Date	Flow (cfs)	Temperature °C	Temperature °F	D.O.[1] (mg/L)	D.O.[1] (% Sat.)	Alkalinity (mg $CaCO_3$/L)	Color (APHA Units)	EC[2] (umhos/cm)	Odor[3]	pH Field	pH Lab	Turbidity (NTU)
04/24/86	2.7	10.0	50	10.4	97	48	-	258	0	7.6	7.7	0.2
05/21/86	1.3	16.7	62	9.5	102	130	-	270	0	7.9	8.3	0.2
06/05/86	1.8	15.6	60	9.3	98	136	-	273	0	8.0	8.3	0.2
06/18/86	1.4	17.2	63	9.9	108	139	-	286	0	7.7	8.2	0.2
07/09/86	0.9	19.4	67	9.5	108	137	-	293	0	7.9	8.2	0.4
07/24/86	0.1	20.6	69	5.4	63	146	-	320	0	6.9	7.2	6.7
08/07/86	0.5	-	-	9.1	-	133	-	308	0	7.8	8.0	0.4
08/21/86	0.6	20.0	68	9.8	113	130	10	305	0	7.9	8.0	0.5
09/11/86	0.6	18.9	66	10.2	115	139	5	287	0	8.0	8.2	1.0
09/25/86	1.0	18.3	65	8.8	98	121	-	306	0	8.2	8.2	0.5
10/10/86	0.8	13.3	56	9.5	95	147	5	331	0	7.7	7.9	0.3
10/24/86	-	11.7	53	8.3	80	152	15	321	0	7.3	8.1	3.3
11/06/86	0.5	11.1	52	9.1	87	152	-	334	0	7.2	8.0	3.5
11/21/86	0.9	8.3	47	9.5	85	152	-	316	0	7.2	7.8	4.3
12/11/86	0.5	6.7	44	10.2	88	151	15	324	0	7.3	7.8	4.0
12/23/86	1.7	6.1	43	10.1	85	131	20	292	0	7.3	7.8	2.4
01/09/87	1.9	3.9	39	10.8	86	113	5	259	0	7.8	7.8	1.0
01/22/87	1.0	4.4	40	12.0	97	131	7	298	0	7.9	7.8	0.3
02/05/87	4.4	8.9	48	10.6	96	85	20	191	0	7.3	7.6	1.0
02/18/87	5.4	7.8	46	11.2	99	77	20	175	0	7.5	7.3	1.3
03/05/87	1.8	7.8	46	10.5	93	106	5	236	0	7.8	7.9	0.5
03/17/87	8.5	10.0	50	10.2	95	69	15	161	0	7.4	7.5	1.8
04/03/87	3.0	8.9	48	11.2	102	97	5	217	0	7.6	7.8	0.4
04/13/87	1.7	13.3	56	10.0	101	110	10	234	0	7.8	7.8	0.3
05/07/87	1.1	18.9	66	7.7	88	126	5	284	0	7.8	8.0	0.5
06/05/87	1.0	16.1	61	9.6	102	135	10	300	0	7.7	8.1	0.2
06/25/87	0.8	17.2	63	9.2	100	138	5	309	0	7.7	8.0	0.2

1/ Dissolved oxygen in milligrams per liter (mg/L) or percent saturation (% Sat.)
2/ Electrical conductivity
3/ (0) none detected, (+) slight odor, (++) strong odor

APPENDIX 1E. PHYSICAL WATER QUALITY CHARACTERISTICS OF THE MIDDLE TRIBUTARY NEAR THE CONFLUENCE WITH MORRIS RESERVOIR

Date	Flow (cfs)	Temperature °C	°F	D.O.[1] (mg/L)	(% Sat.)	Alkalinity (mg $CaCO_3$/L)	Color (APHA Units)	EC[2] (umhos/cm)	Odor[3]	pH Field	Lab	Turbidity (NTU)
04/24/86	<1.0	13.9	57	6.3	64	41	-	117	0	6.6	7.9	1.4
12/23/86	0.3	6.7	44	10.9	94	38	60	126	0	6.9	7.1	13
01/09/87	0.4	3.3	38	10.8	85	35	30	114	0	6.8	6.7	5.0
01/22/87	<0.1	3.9	39	9.8	78	41	15	132	0	6.7	6.6	0.7
02/05/87	0.8	9.4	49	10.1	93	36	45	94	0	7.0	7.3	5.3
02/18/87	1.0	7.8	46	10.8	95	33	45	88	0	7.1	7.1	6.8
03/04/87	0.2	7.8	46	9.8	86	36	15	109	0	7.0	7.0	1.8
03/17/87	1.4	10.6	51	10.2	96	34	40	87	0	7.2	7.1	7.3
04/03/87	0.2	8.6	47	10.0	89	39	10	114	0	7.2	7.1	1.2
04/13/87	-	15.0	59	5.8	60	39	10	114	0	6.8	6.8	0.7

1/ Dissolved oxygen in milligrams per liter (mg/L) or percent saturation (% Sat.)
2/ Electrical conductivity
3/ (0) none detected, (+) slight odor, (++) strong odor

APPENDIX 1F. PHYSICAL WATER QUALITY CHARACTERISTICS OF THE EAST TRIBUTARY NEAR THE CONFLUENCE WITH MORRIS RESERVOIR

Date	Flow (cfs)	Temperature °C	°F	D.O.[1] (mg/L)	(% Sat.)	Alkalinity (mg $CaCO_3$/L)	Color (APHA Units)	EC[2] (umhos/cm)	Odor[3]	pH Field	Lab	Turbidity (NTU)
04/24/86	-	10.0	50	11.0	102	125	-	118	0	7.3	8.3	0.7
05/21/86	0.2	14.4	58	9.3	96	56	-	133	0	7.8	7.9	0.5
06/05/86	0.1	15.0	59	8.4	87	69	-	140	0	7.2	7.8	0.8
06/18/86	<0.1	16.1	61	8.2	87	63	-	156	0	7.1	7.3	0.5
12/23/86	0.8	6.1	43	10.1	85	42	40	132	0	7.0	7.1	6.9
01/09/87	0.7	3.9	39	11.4	91	41	20	120	0	7.1	7.1	3.0
01/22/87	0.1	3.3	38	10.7	84	44	10	137	0	6.9	6.9	0.5
02/05/87	2.0	7.2	45	11.3	98	32	40	85	0	7.3	7.1	7.0
02/18/87	2.3	7.2	45	11.4	99	36	40	92	0	7.3	7.1	5.5
03/04/87	0.8	7.2	45	11.1	97	45	15	119	0	7.4	7.3	2.8
03/17/87	3.5	8.9	48	11.1	101	36	35	89	0	7.3	7.1	5.8
04/03/87	0.7	7.7	46	10.9	96	44	10	121	0	7.2	7.2	1.5
04/13/87	-	13.3	56	10.4	104	48	15	124	0	7.5	7.3	0.8
05/07/87	-	21.1	70	8.4	99	60	5	165	0	7.3	7.5	0.5

1/ Dissolved oxygen in milligrams per liter (mg/L) or percent saturation (% Sat.)
2/ Electrical conductivity
3/ (0) none detected, (+) slight odor, (++) strong odor

APPENDIX 1G. PHYSICAL WATER QUALITY CHARACTERISTICS OF UNTREATED WATER FROM THE CITY OF WILLITS WATER TREATMENT PLANT

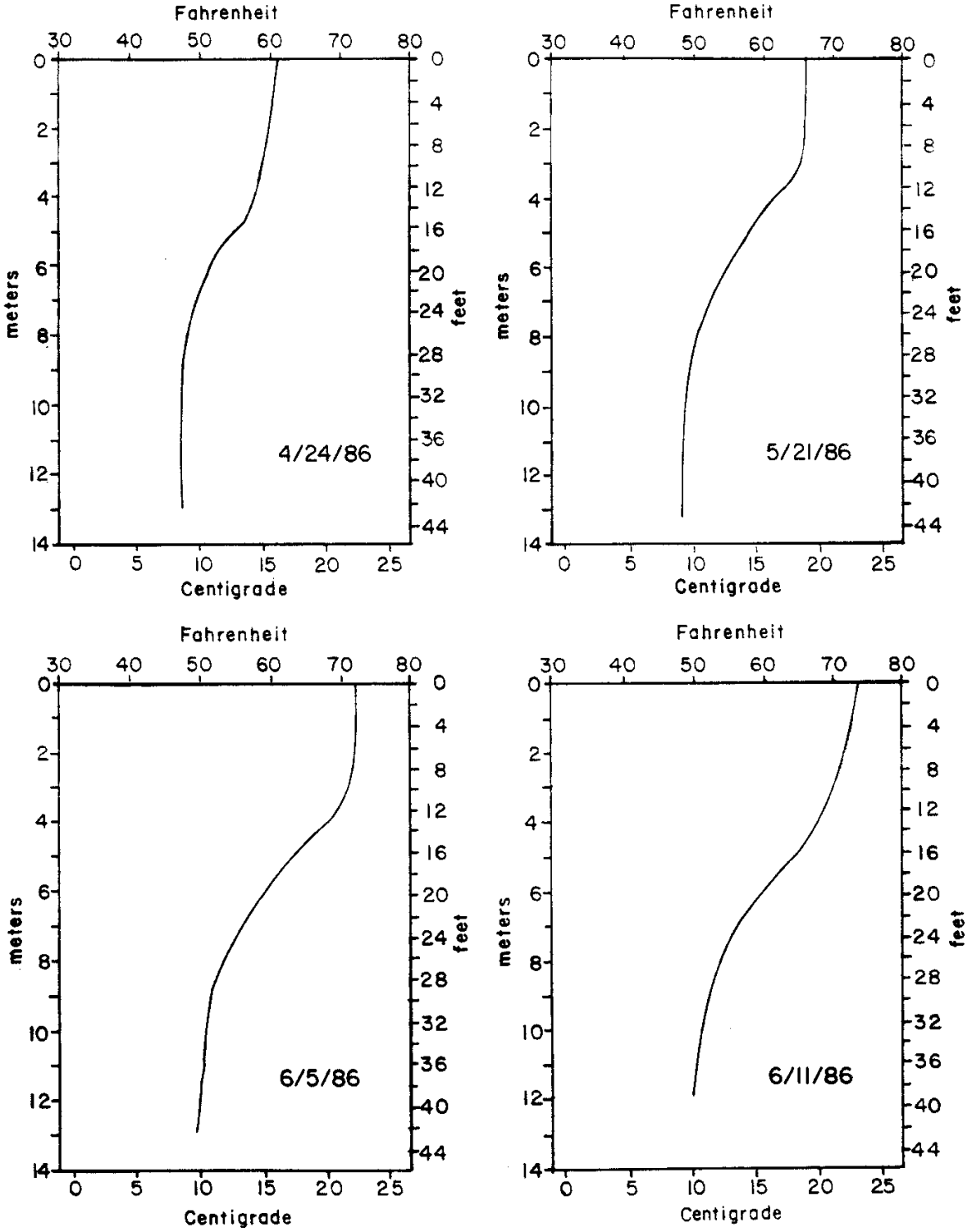
Date	Temperature °C	Temperature °F	D.O.[1] (mg/L)	D.O.[1] (% Sat.)	Alkalinity (mg $CaCO_3$/L)	Color (APHA Units)	EC[2] (umhos/cm)	Odor[3]	pH Field	pH Lab	Turbidity (NTU)
05/21/86	15.0	59.0	4.3	45	75	-	165	-	7.0	7.8	2.5
06/05/86	22.2	72.0	1.6	19	78	-	161	-	6.9	7.2	1.3
06/18/86	18.3	65.0	2.5	28	79	-	176	-	6.9	7.1	1.9
07/09/86	23.6	74.5	1.5	19	92	-	207	-	7.0	7.4	1.8
07/24/86	27.2	81.0	0.1	1	99	-	226	-	7.0	7.2	1.1
08/07/86	26.1	79.0	0.2	3	100	-	240	-	7.0	7.3	1.5
08/21/86	25.6	78.0	0.0	0	117	40	270	-	7.1	7.2	4.3
09/12/86	22.2	72.0	2.6	31	125	25	255	-	7.4	7.6	4.0
09/25/86	16.1	61.0	1.0	11	121	-	282	-	7.2	7.4	1.4
10/10/86	17.8	64.0	4.5	50	129	20	291	-	7.1	7.4	2.7
10/23/86	16.1	61.0	6.3	67	133	20	279	-	7.3	8.0	2.6
11/06/86	13.1	55.5	5.9	59	137	-	294	-	7.2	7.9	3.5
11/21/86	11.7	53.0	7.5	73	136	-	279	-	7.2	7.7	2.8
12/11/86	6.4	43.5	7.8	66	142	10	312	-	7.3	7.7	2.1
12/23/86	9.4	49.0	7.1	65	128	20	295	-	7.3	7.8	4.0
01/09/87	6.9	44.5	9.1	79	78	50	193	-	7.2	7.4	13
01/21/87	6.4	43.5	8.1	69	81	50	205	-	7.2	7.2	9.3
02/05/87	9.4	49.0	10.3	94	56	60	136	-	7.2	7.4	13
02/18/87	8.3	47.0	9.6	86	44	90	114	-	7.2	7.1	20
03/05/87	8.9	48.0	9.6	87	49	60	131	-	7.2	7.1	11
03/17/87	-	-	9.7	-	42	80	110	-	7.1	7.1	14
04/02/87	12.8	55.0	8.6	85	50	45	133	-	7.1	7.2	8.1
04/13/87	11.7	53.0	8.5	82	52	40	124	-	7.2	7.1	6.5
05/07/87	17.2	63.0	4.9	53	58	45	155	-	7.0	7.2	6.8
06/05/87	17.2	63.0	1.0	11	63	35	167	-	6.8	7.1	2.1
06/25/87	16.1	61.0	1.2	13	64	35	171	-	6.8	7.2	3.3

1/ Dissolved oxygen in milligrams per liter (mg/L) or percent saturation (% Sat.)
2/ Electrical conductivity
3/ (0) none detected, (+) slight odor, (++) strong odor

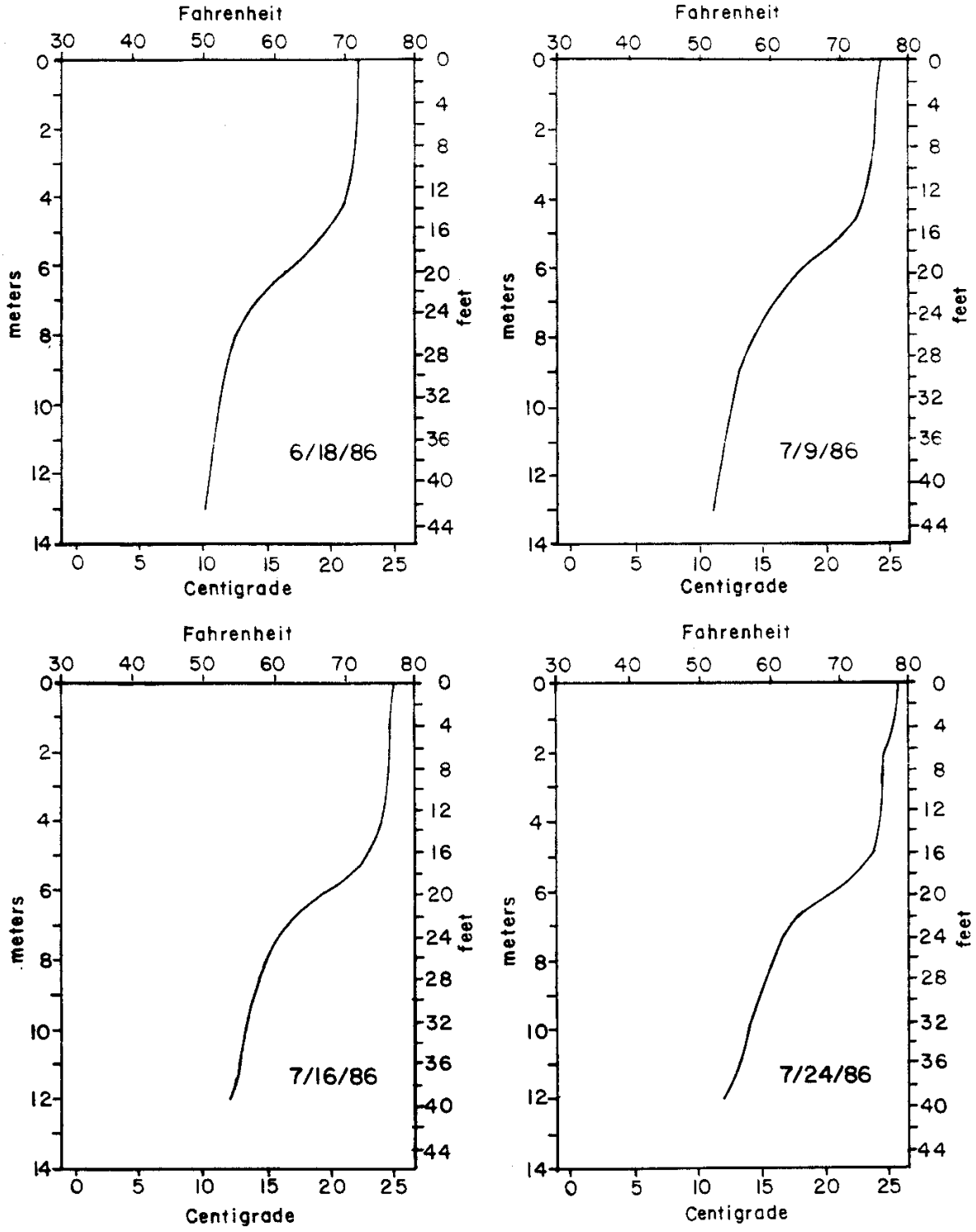
APPENDIX 1H. PHYSICAL WATER QUALITY CHARACTERISTICS OF WATER FROM THE HYPOLIMNETIC PUMP AT MORRIS DAM

Date	Temperature °C	Temperature °F	Alkalinity (mg $CaCO_3$/L)	Color (APHA Units)	EC[2/] (umhos/cm)	Odor[3/]	pH Field	pH Lab	Turbidity (NTU)
06/05/86	12.8	55.0	-	-	-	0	-	-	-
06/18/86	13.9	57.0	-	-	-	0	-	-	-
07/09/86	14.9	58.8	-	-	-	+	-	-	-
07/24/86	16.8	62.2	-	-	-	+	-	-	-
08/07/86	20.2	68.4	101	-	238	+	7.1	7.3	3.4
08/21/86	21.1	70.0	110	40	251	+	7.0	7.2	2.7
09/11/86[3/]						0			

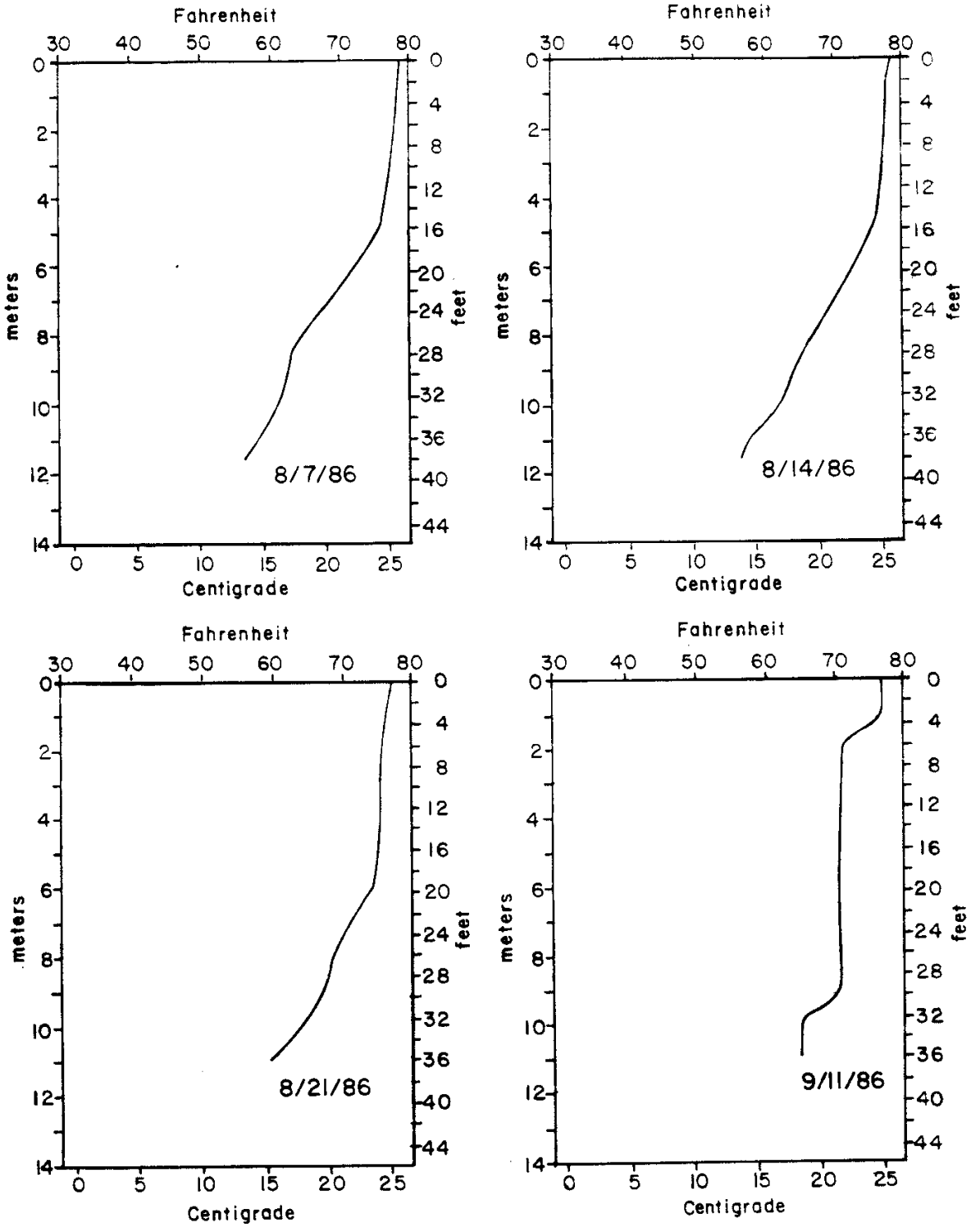
1/ Electrical conductivity
2/ (0) none detected, (+) slight odor, (++) strong odor
3/ Pump not operating from this date onward



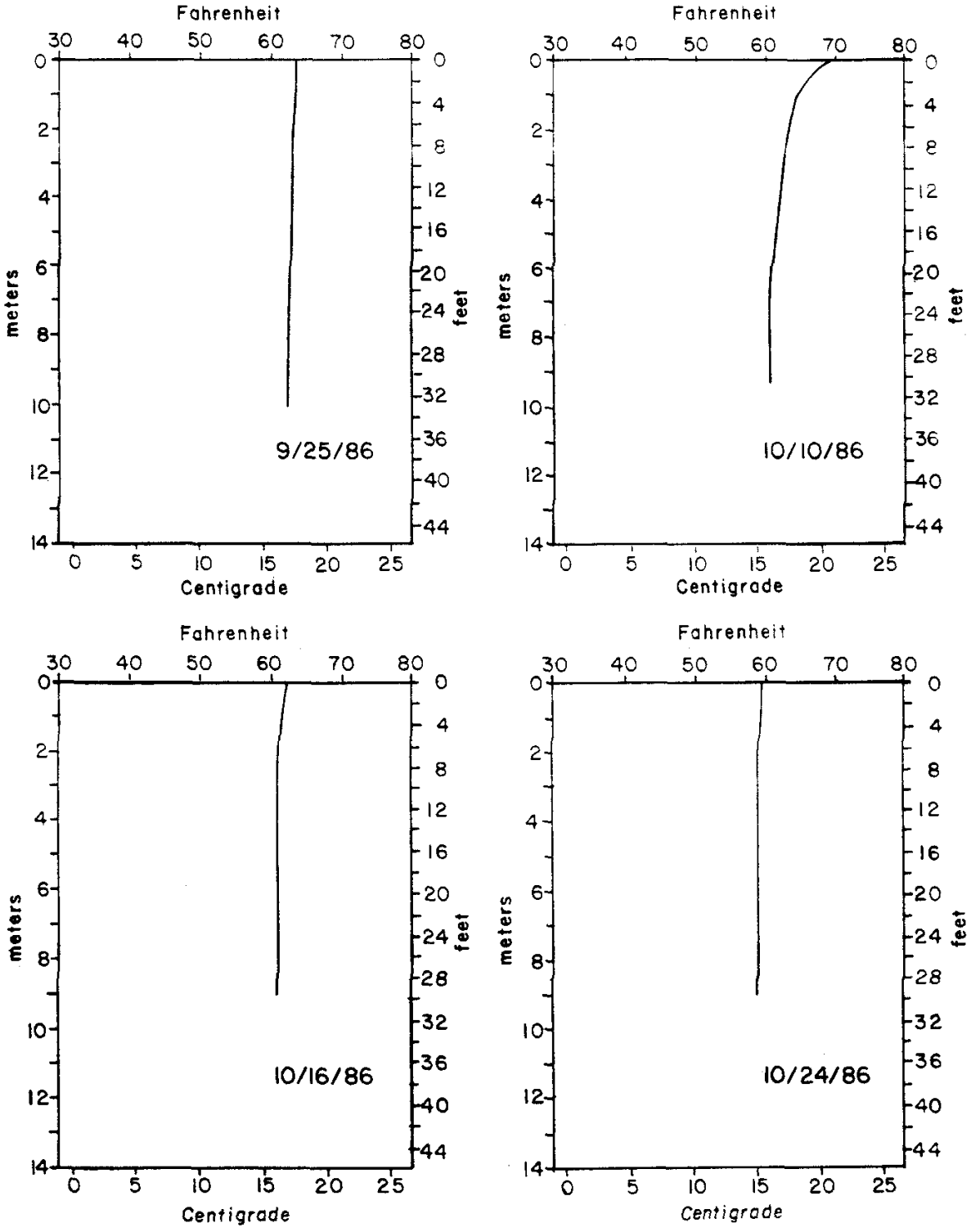
Appendix 2a. Temperature profiles for Morris Reservoir near the dam.



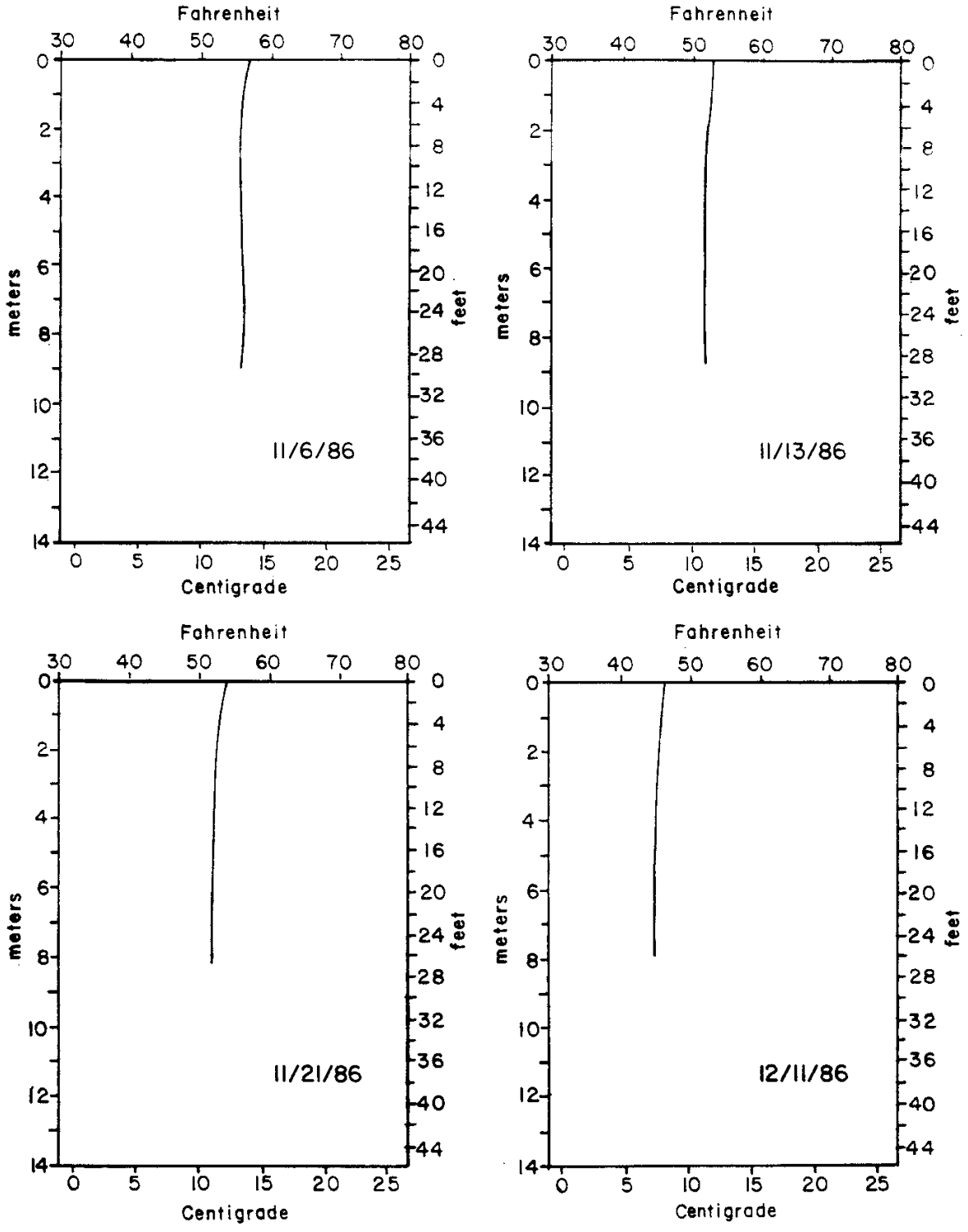
Appendix 2a. continued.



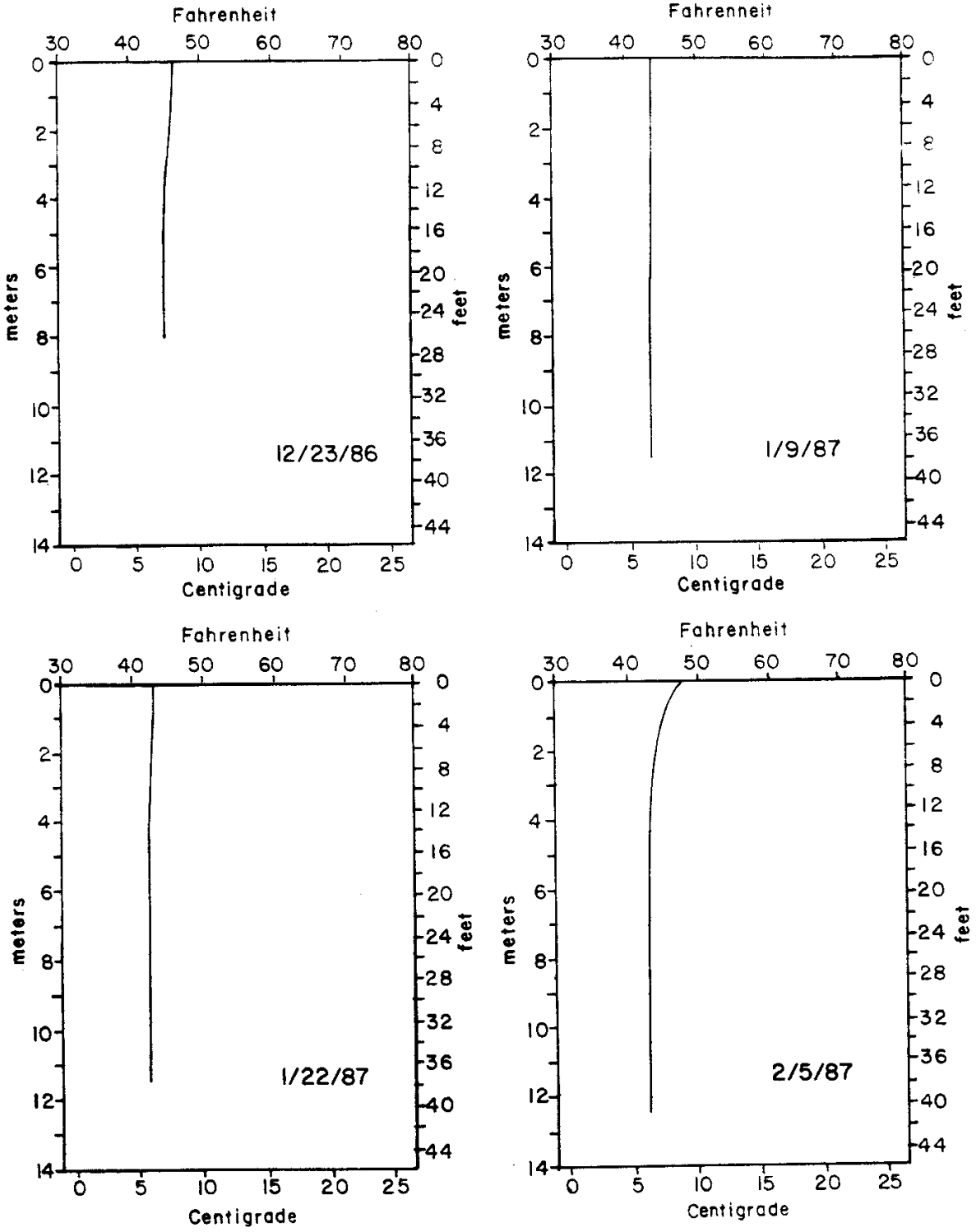
Appendix 2a. continued.



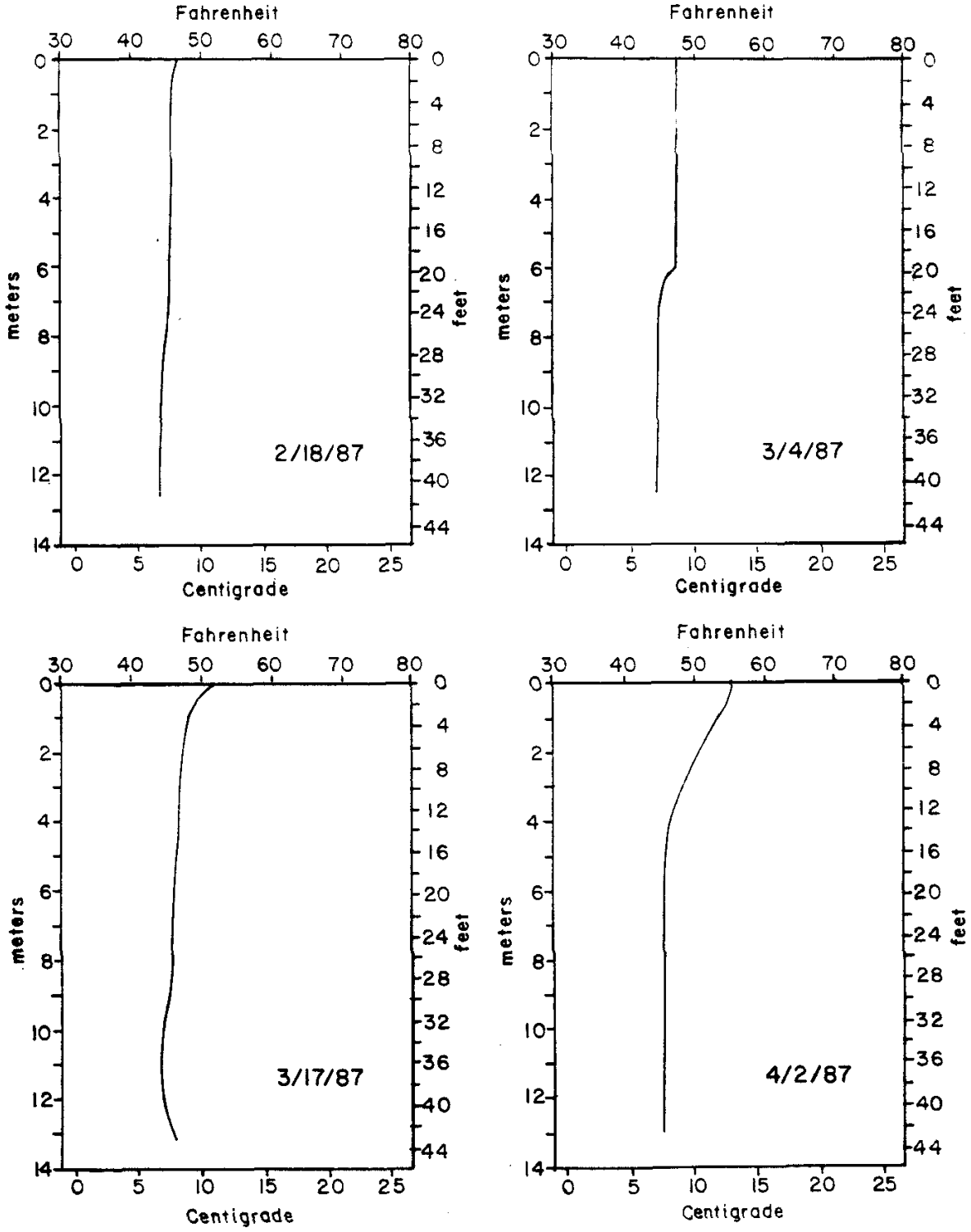
Appendix 2a. continued.



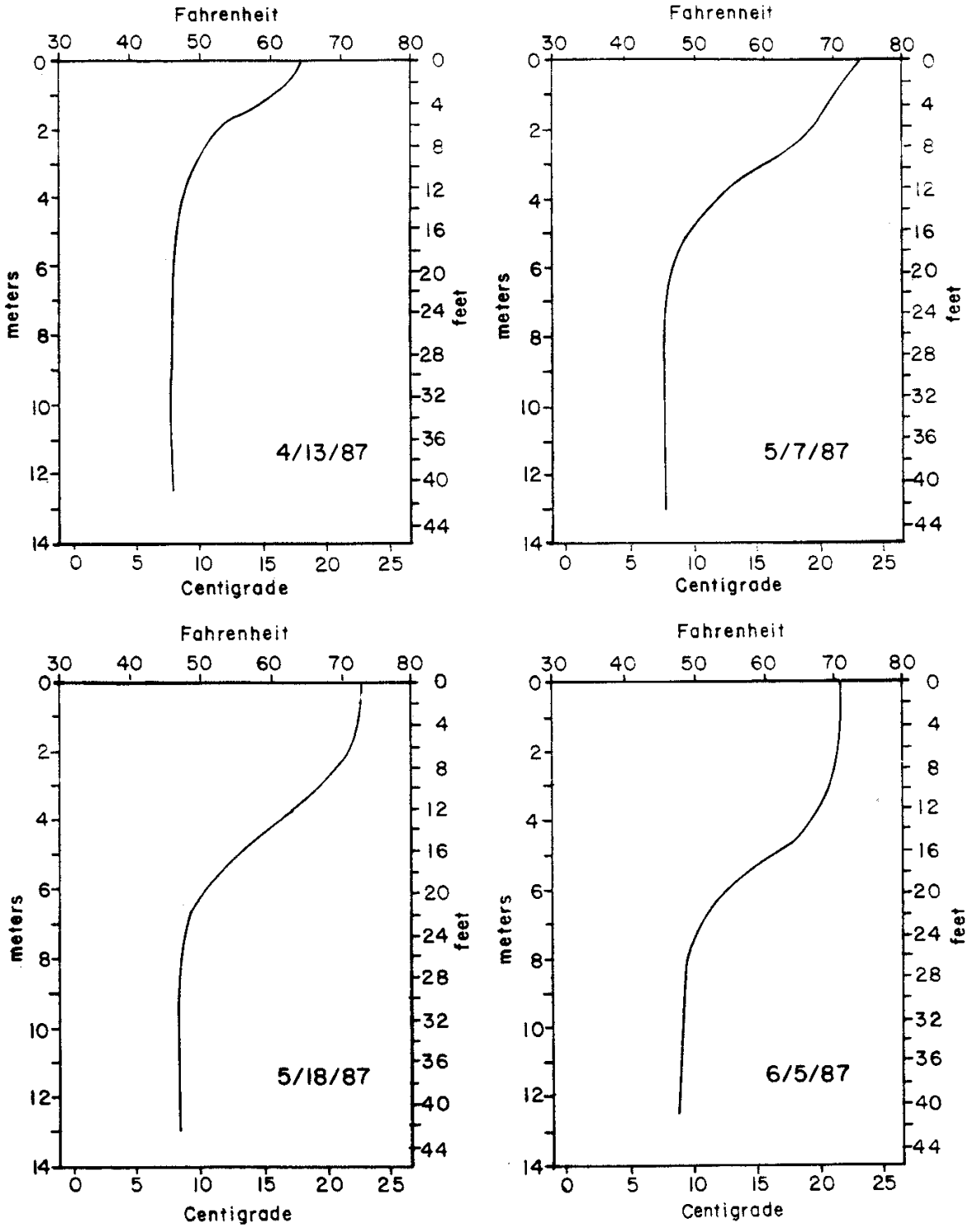
Appendix 2a. continued.



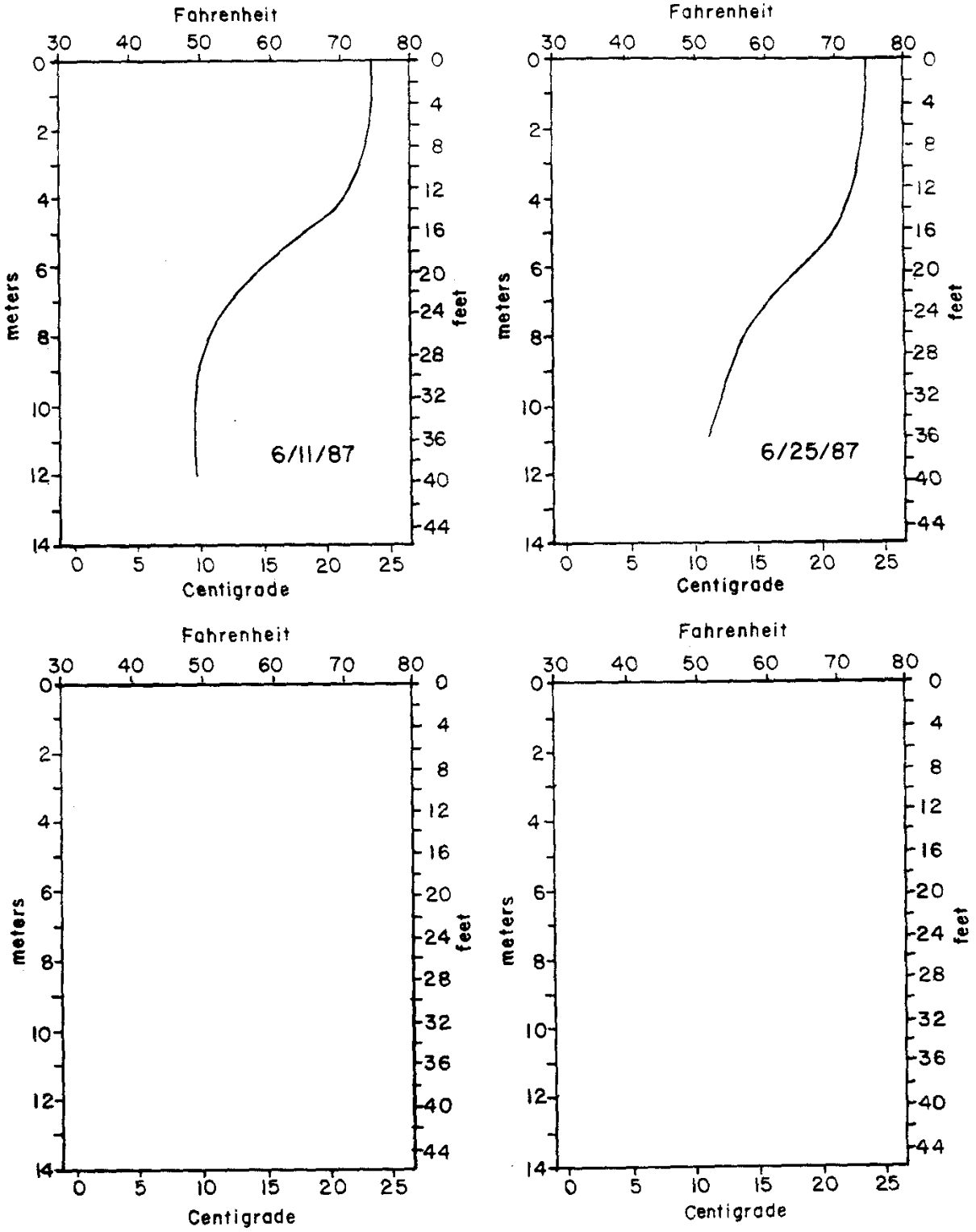
Appendix 2a. continued.



Appendix 2a. continued.



Appendix 2a. continued.



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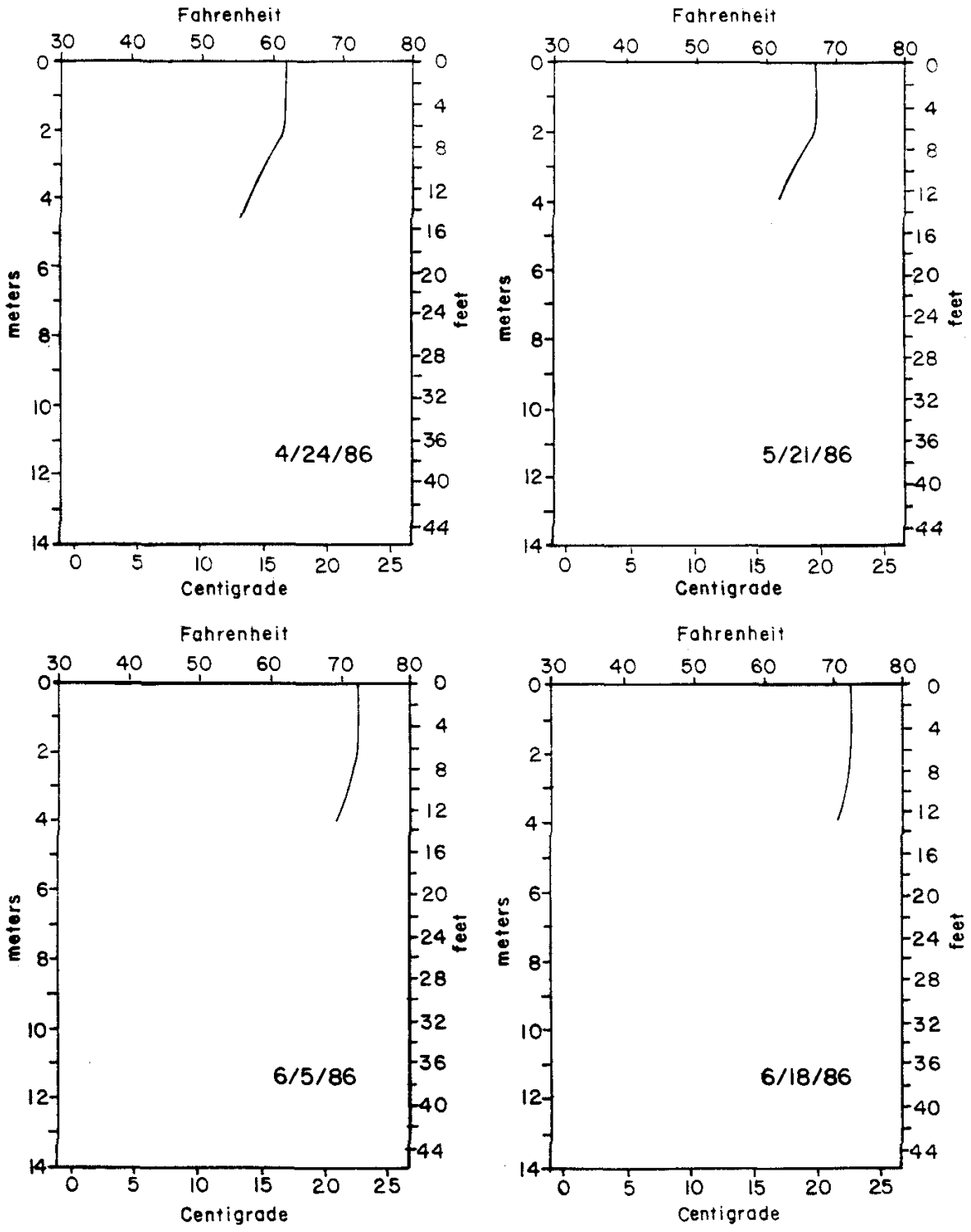
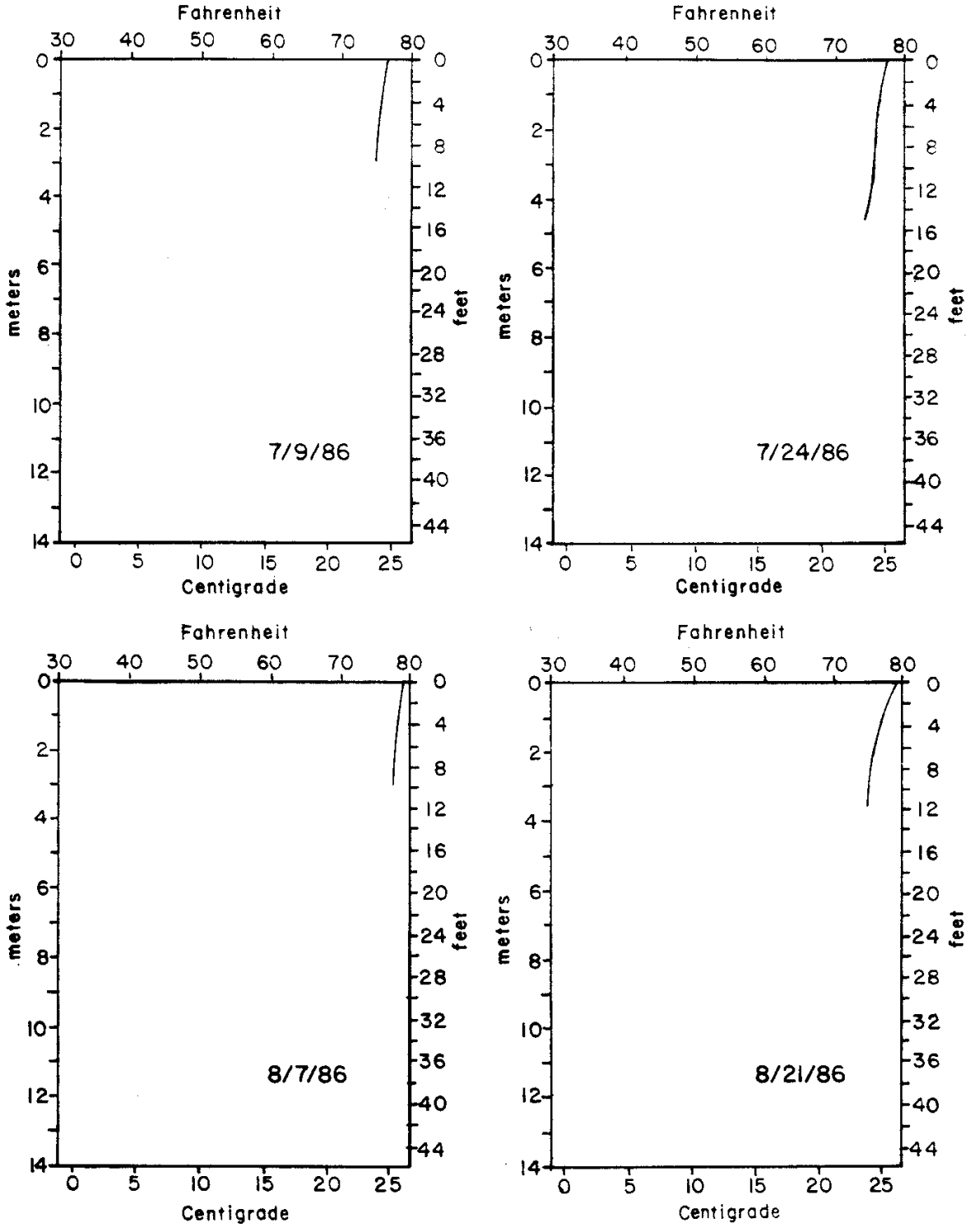
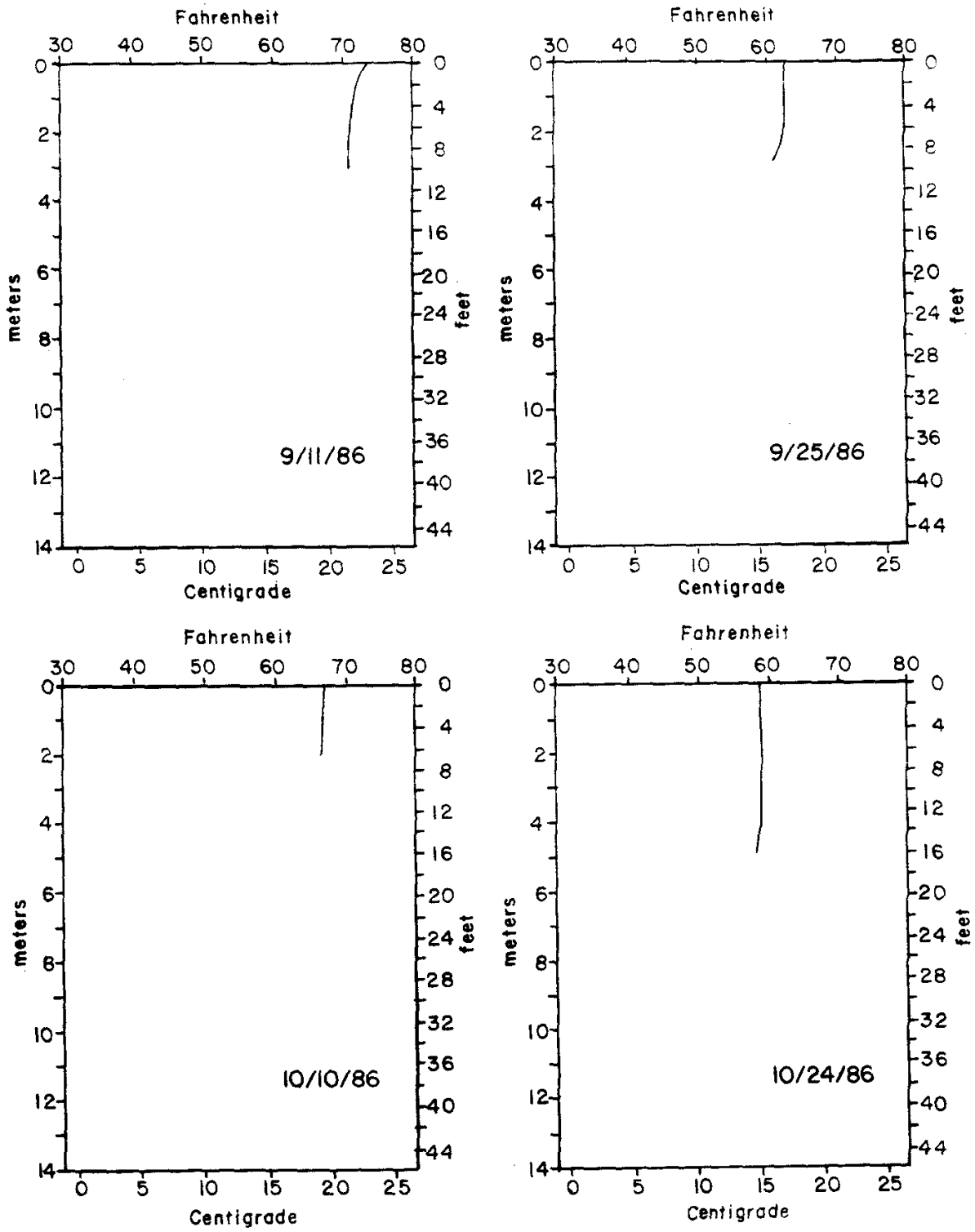


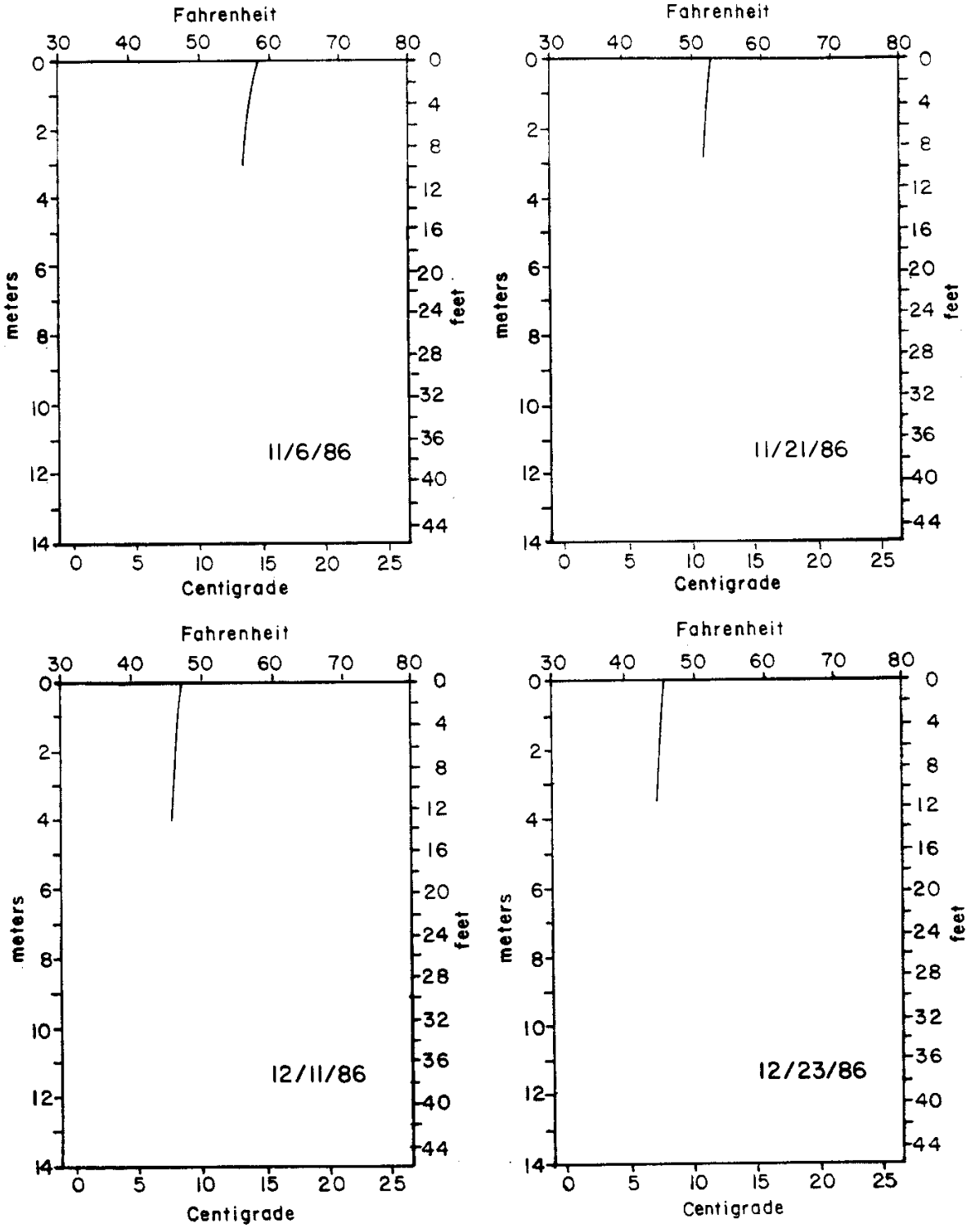
Appendix 2b. Temperature profiles for Morris Reservoir in the Davis Creek arm.



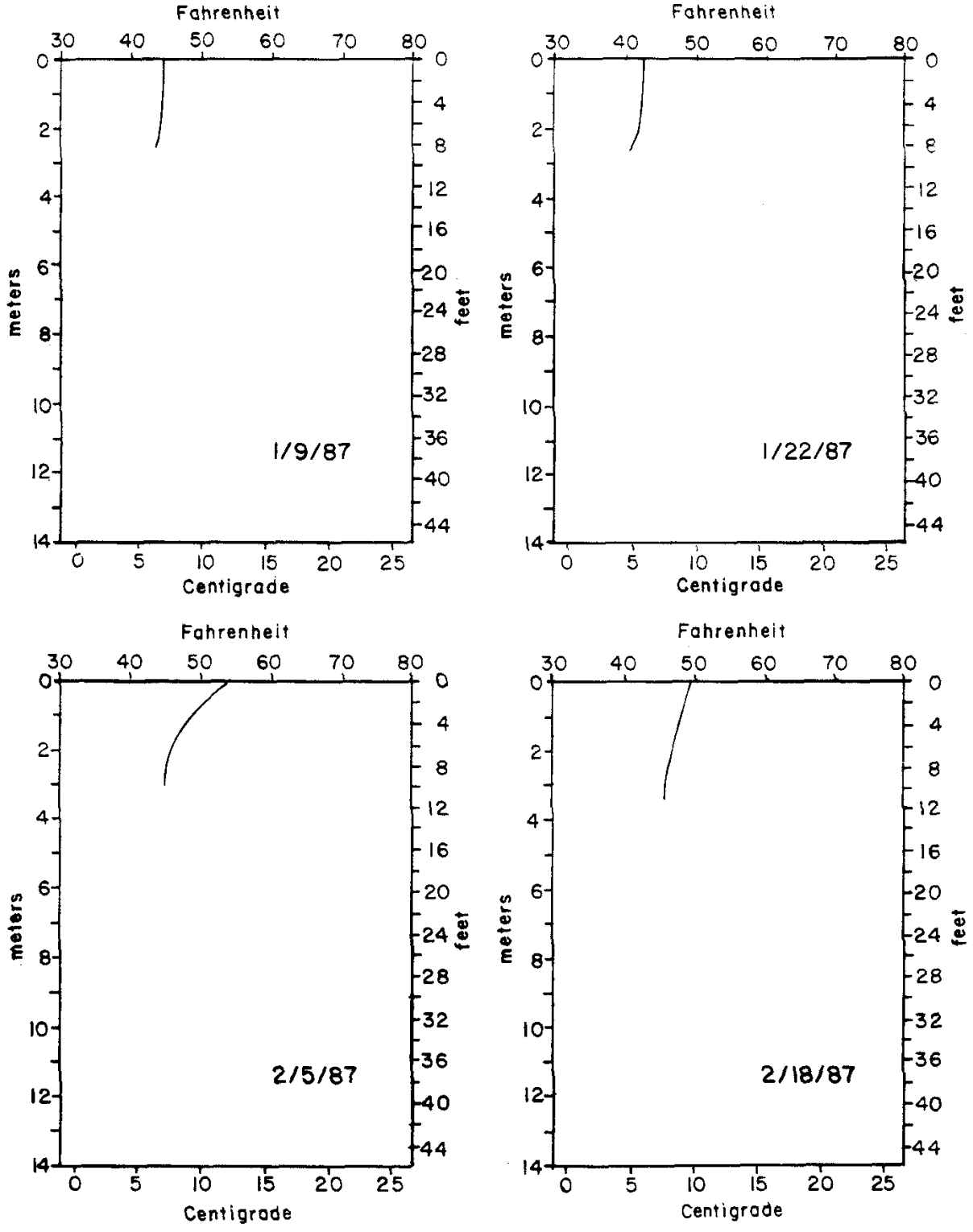
Appendix 2b. continued.



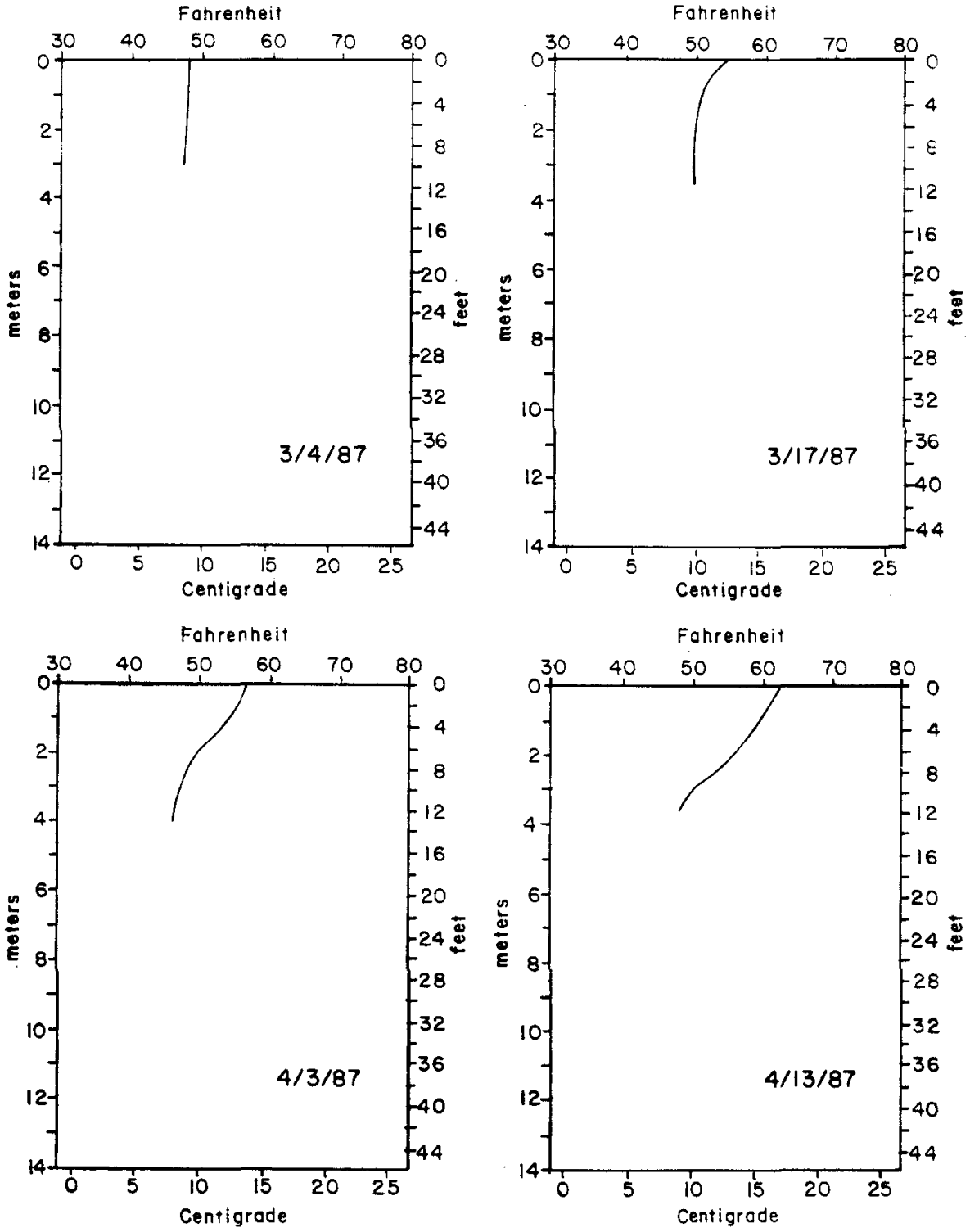
Appendix 2b. continued.



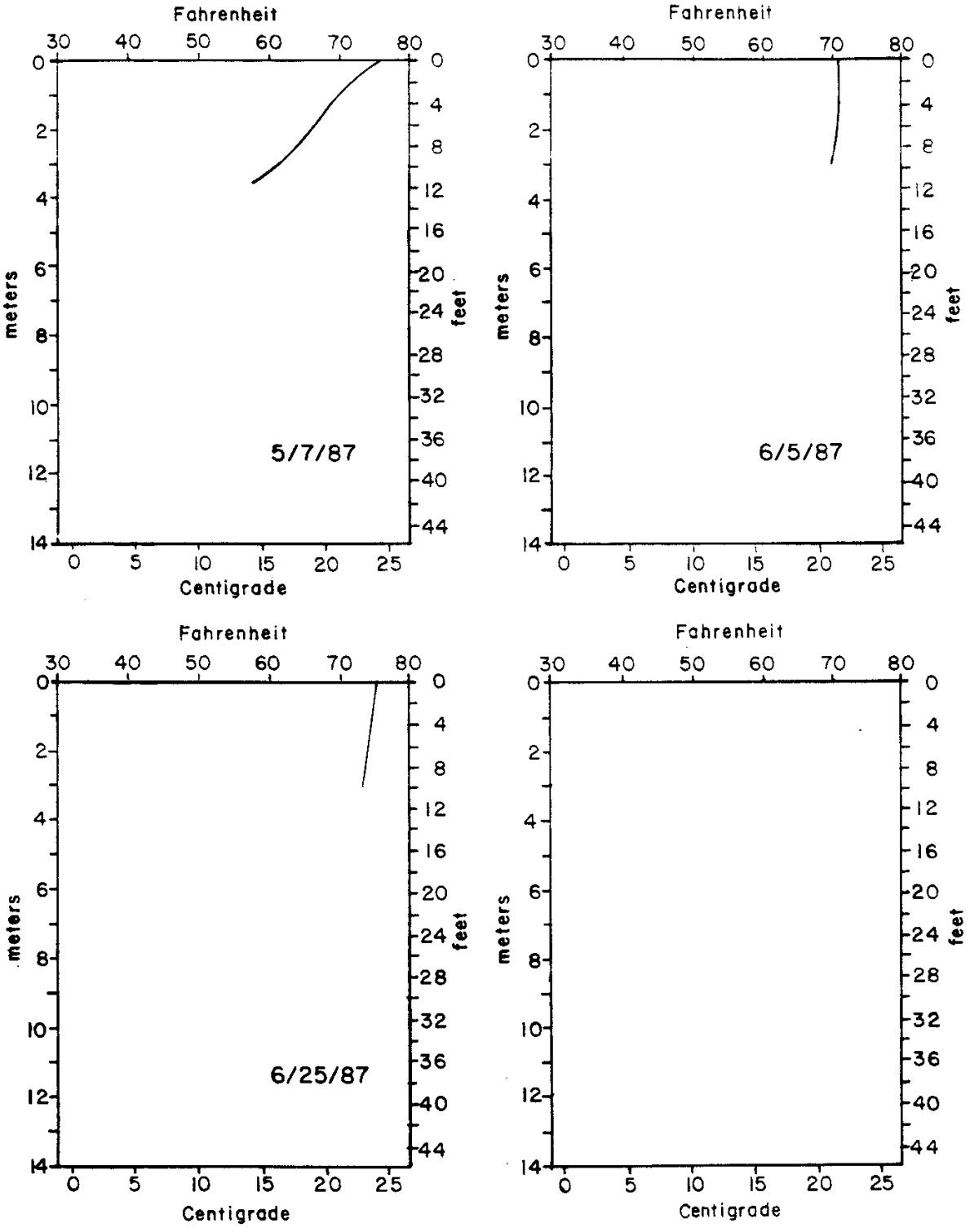
Appendix 2b. continued.



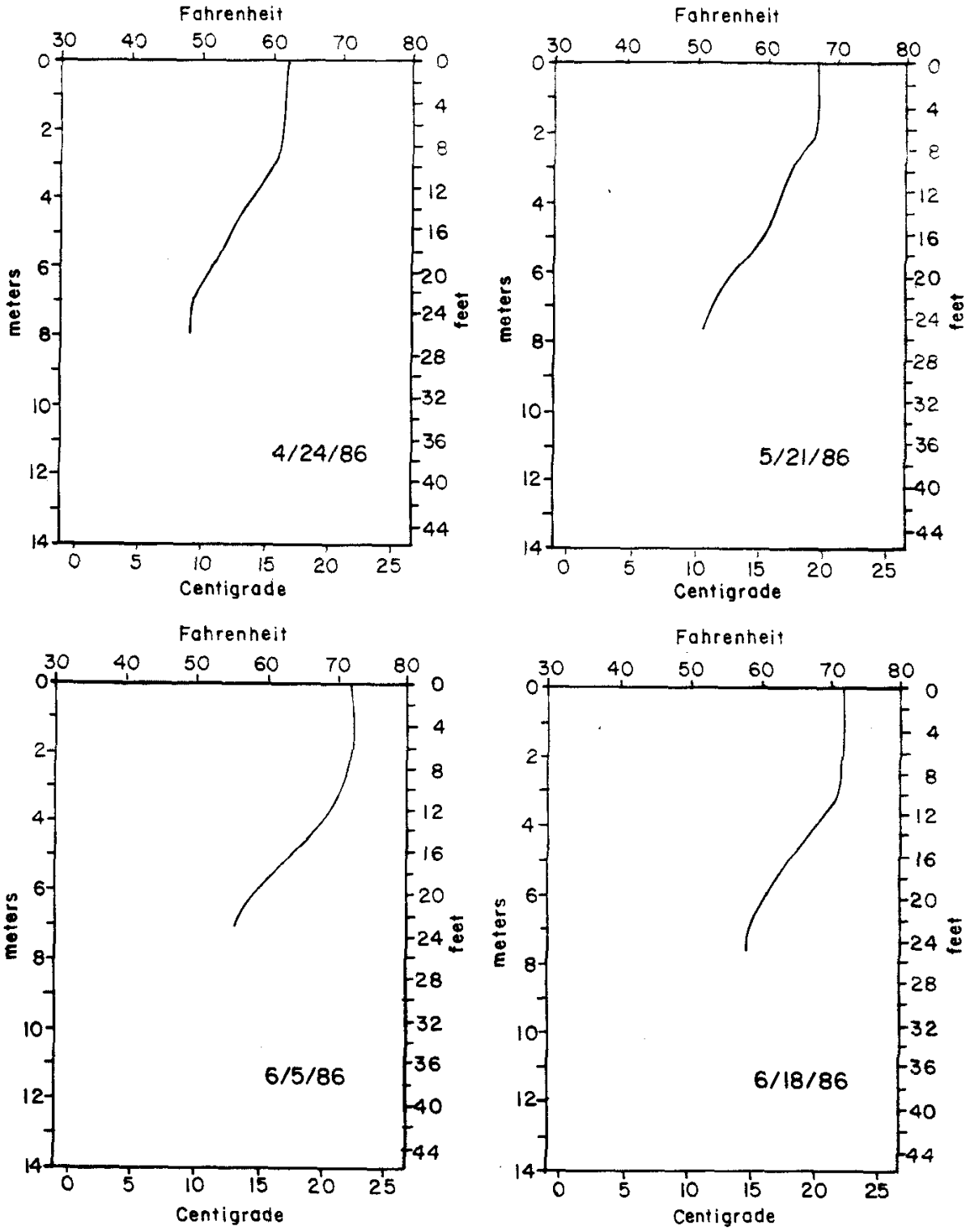
Appendix 2b. continued.



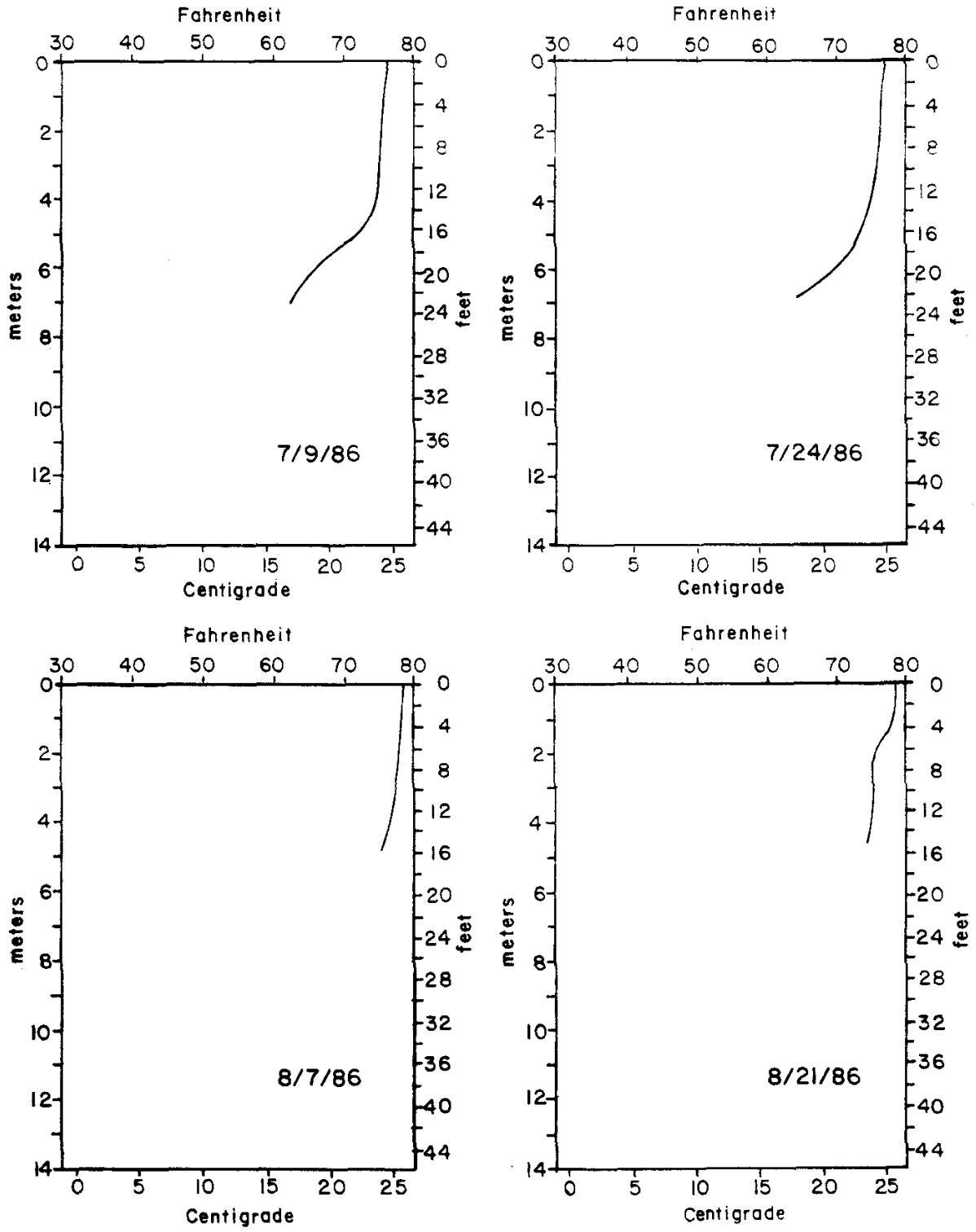
Appendix 2b. continued.



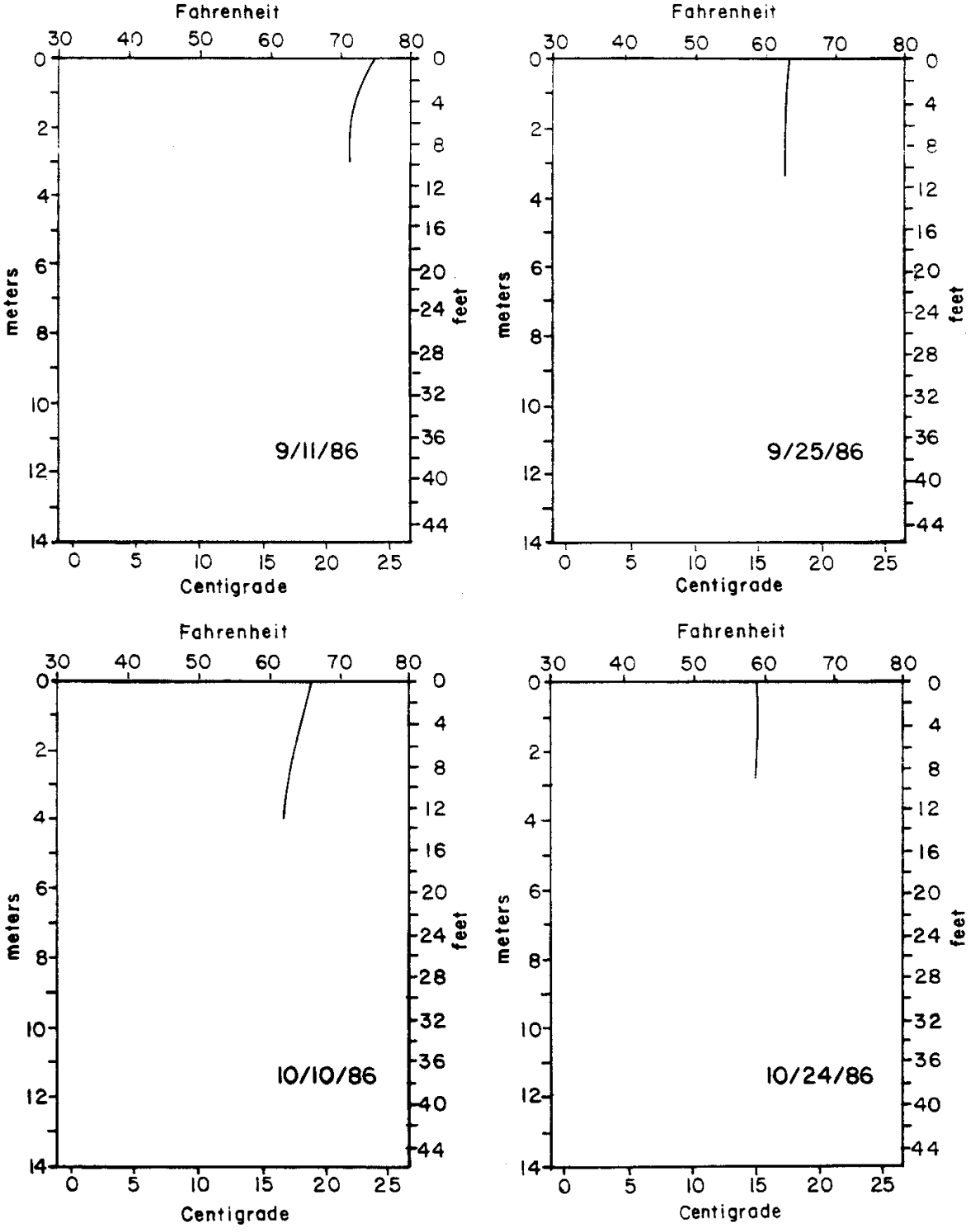
Appendix 2b. continued.



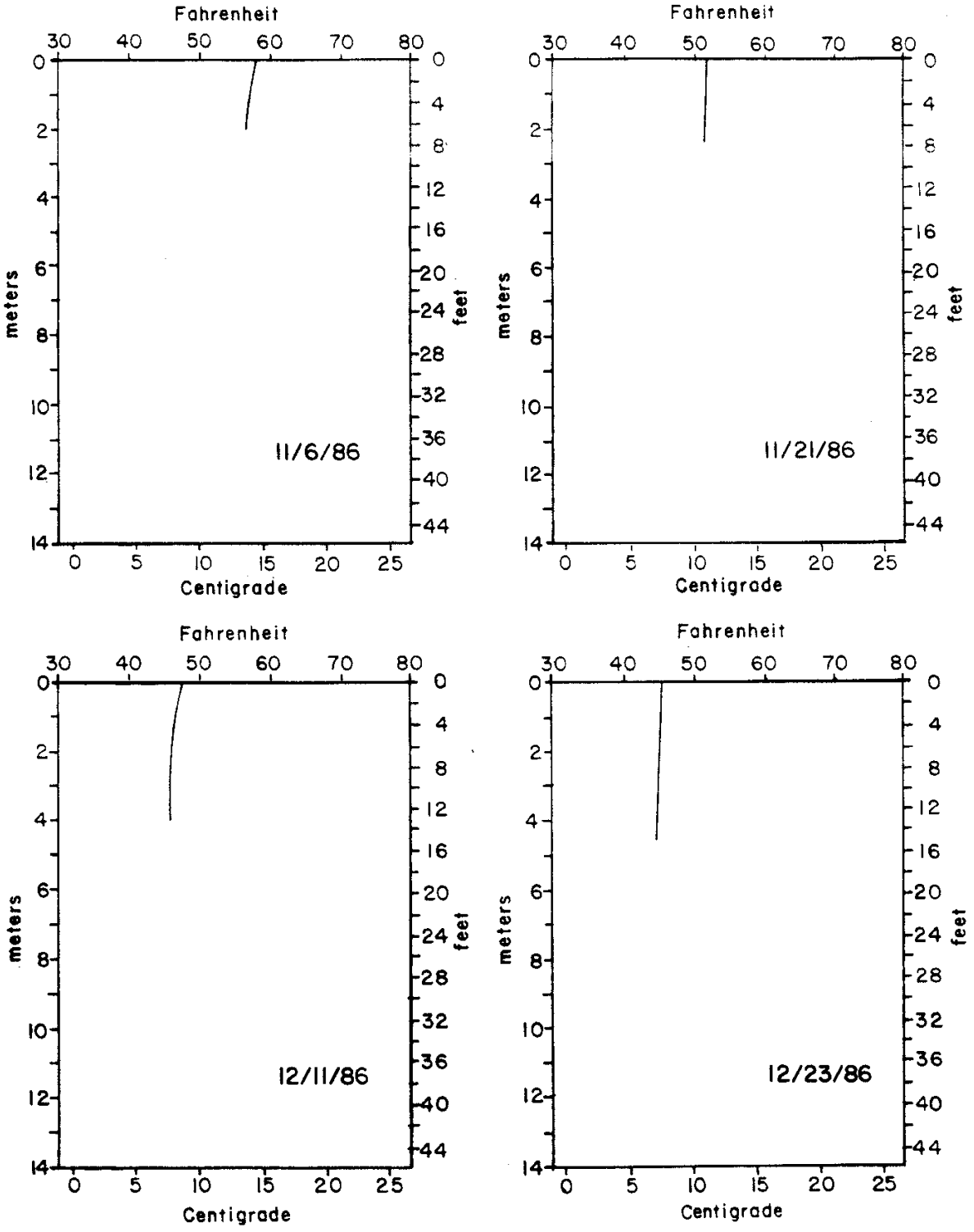
Appendix 2c. Temperature profiles for Morris Reservoir in the east arm.



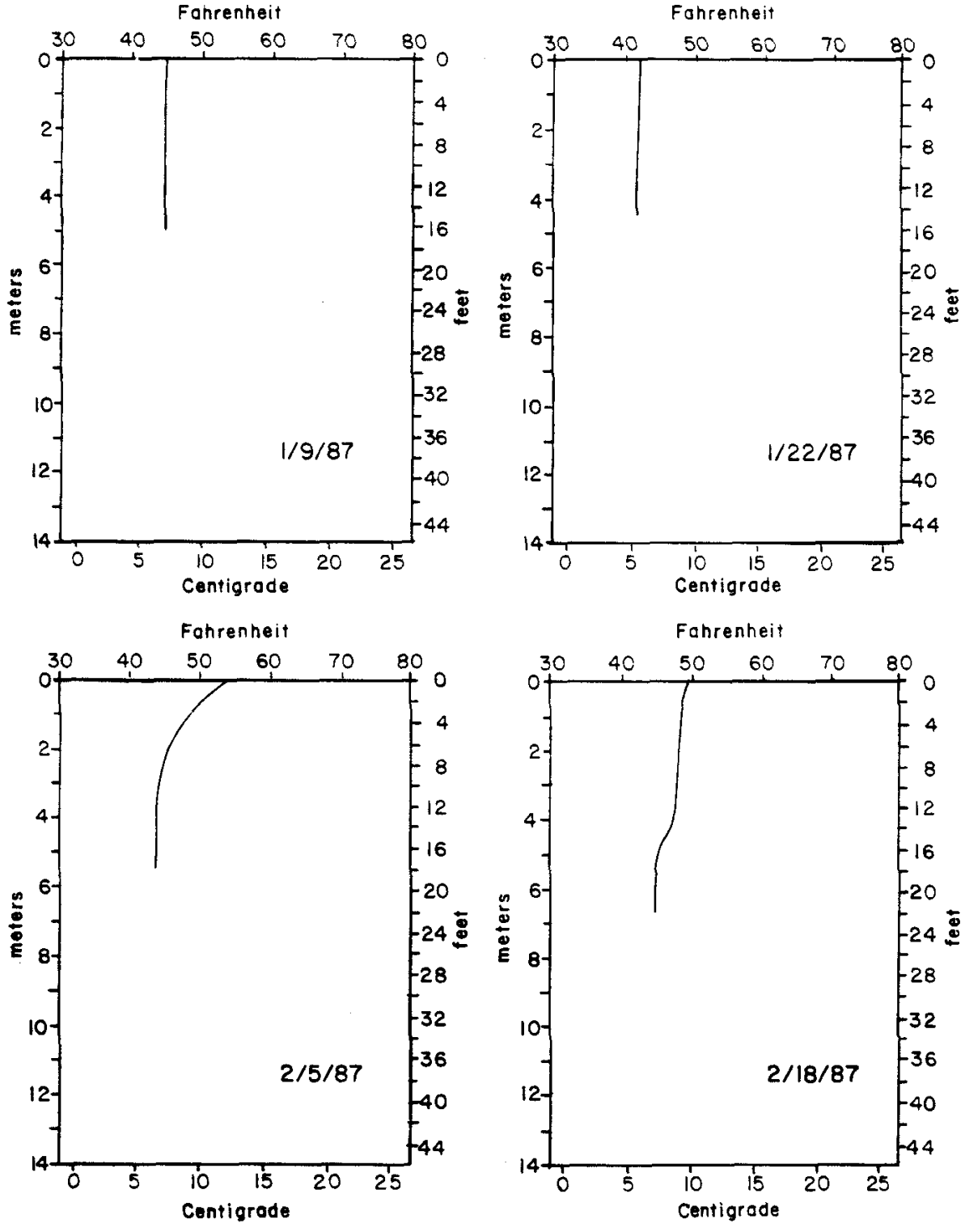
Appendix 2c. continued.



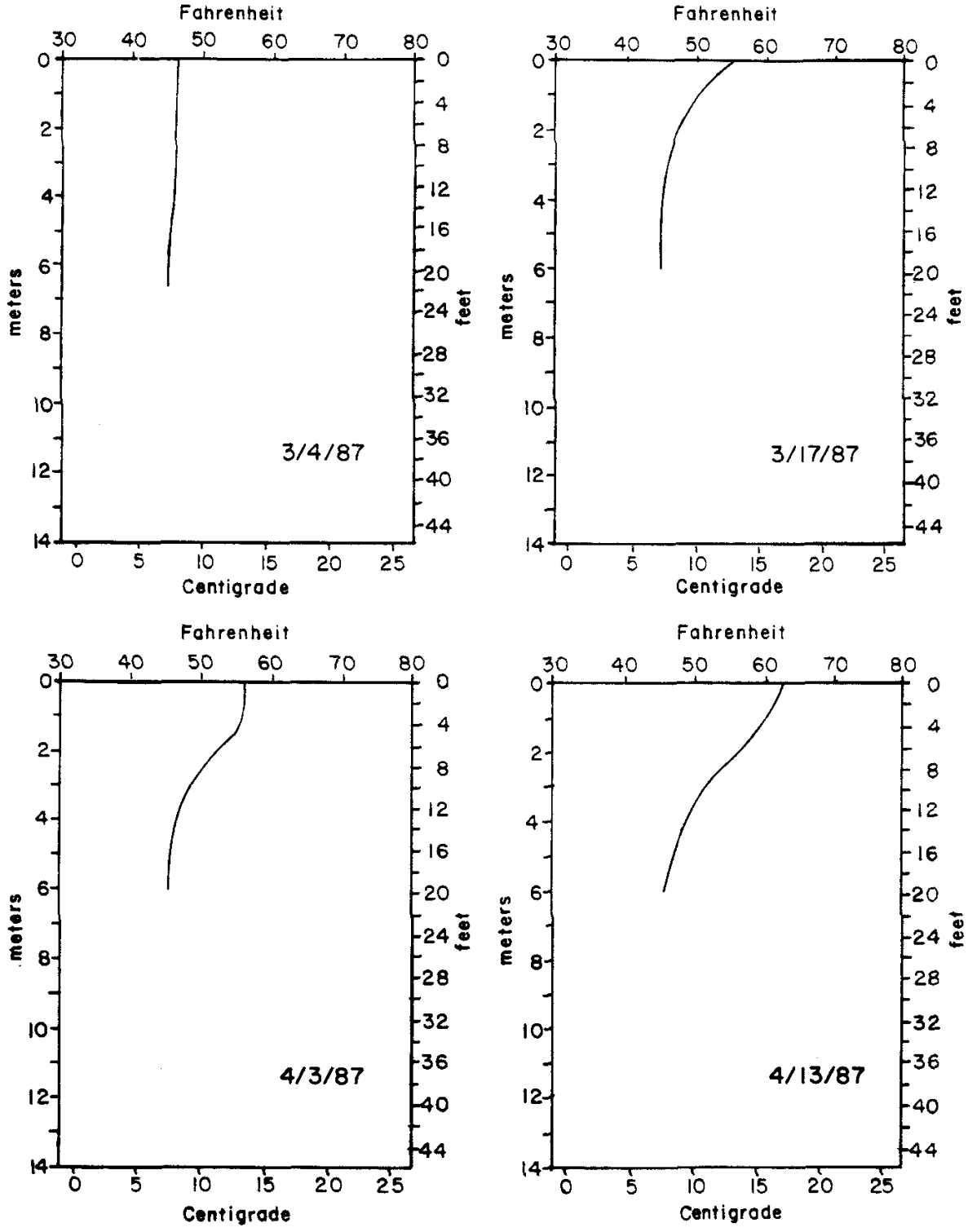
Appendix 2c. continued.



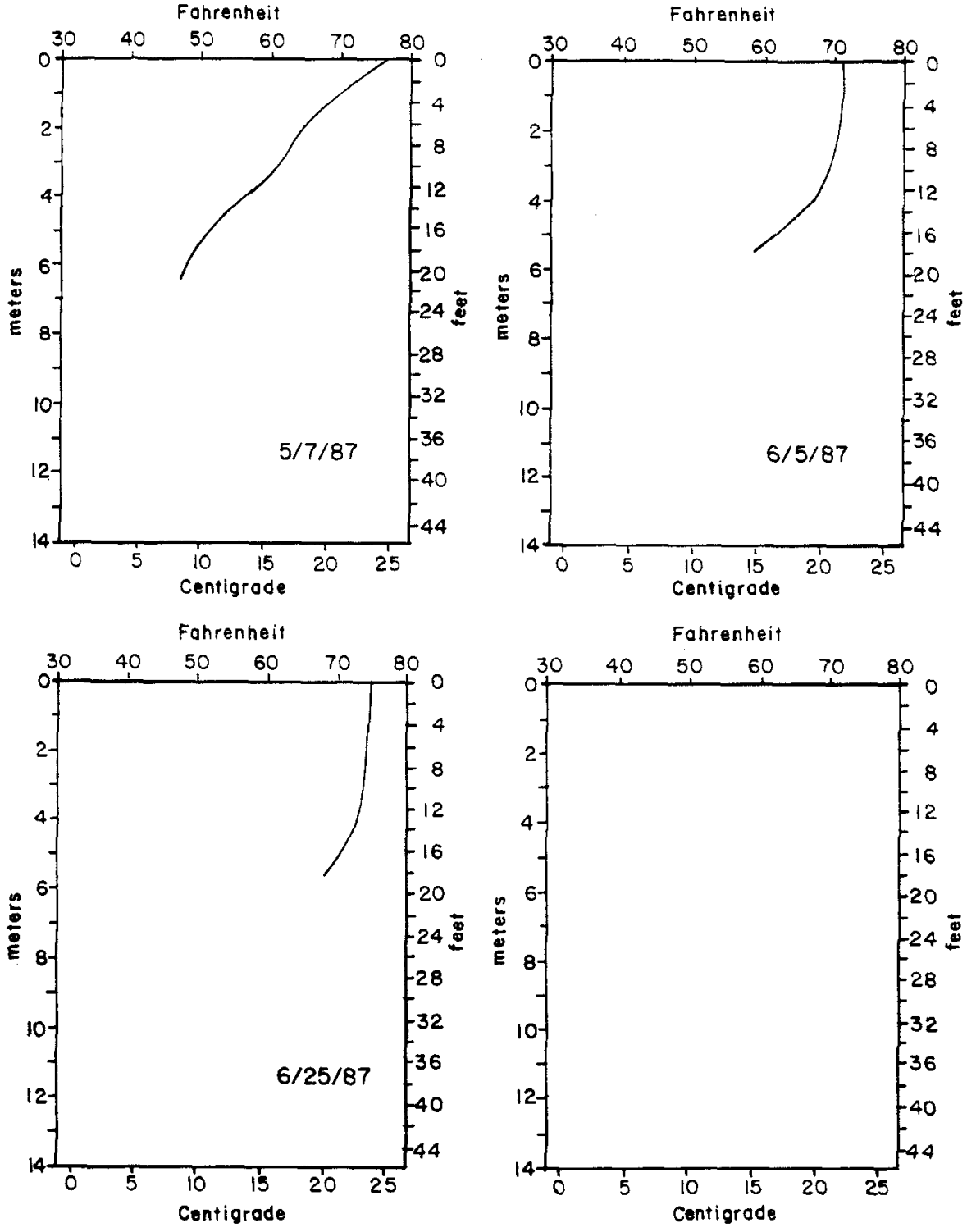
Appendix 2c. continued.



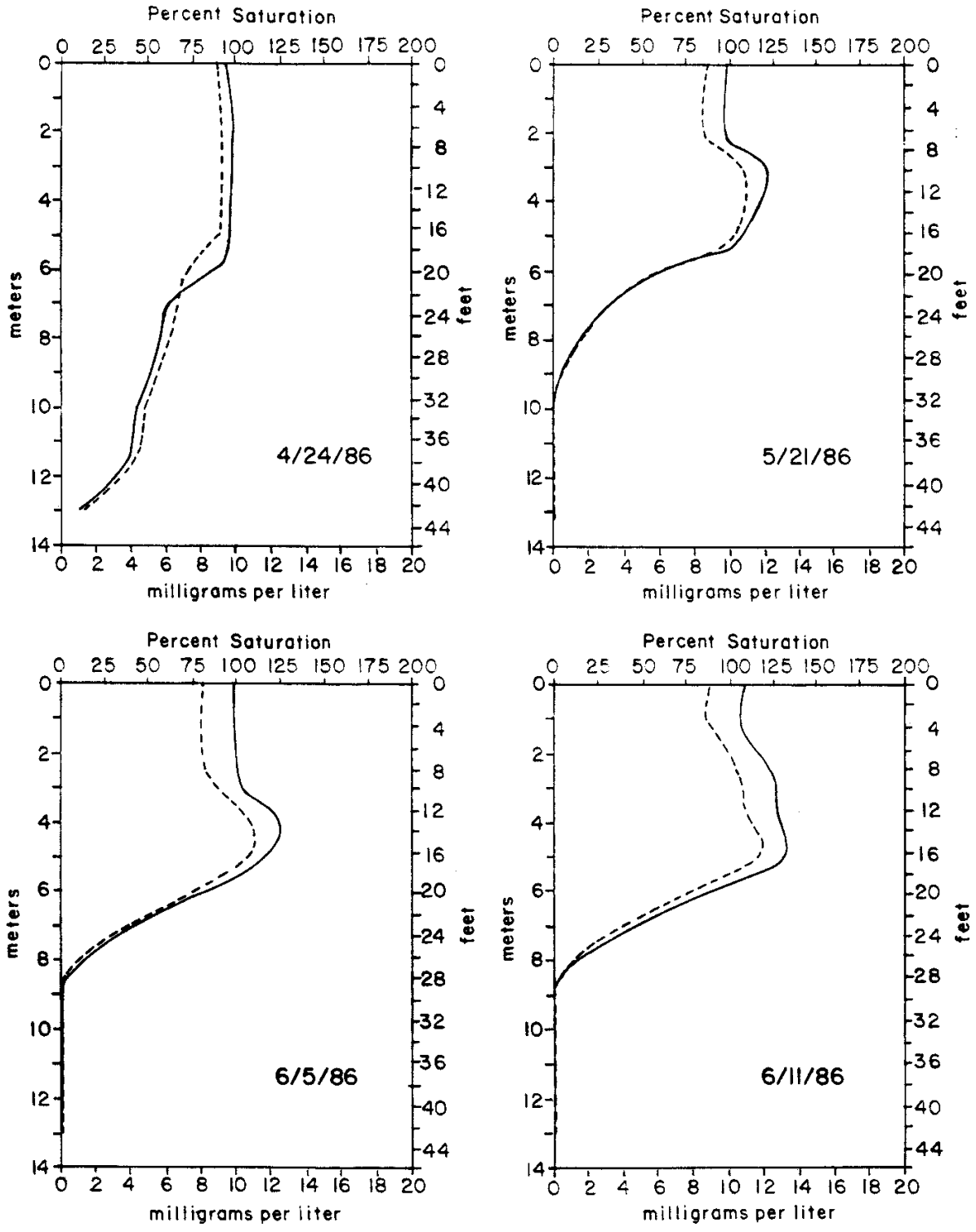
Appendix 2c. continued.



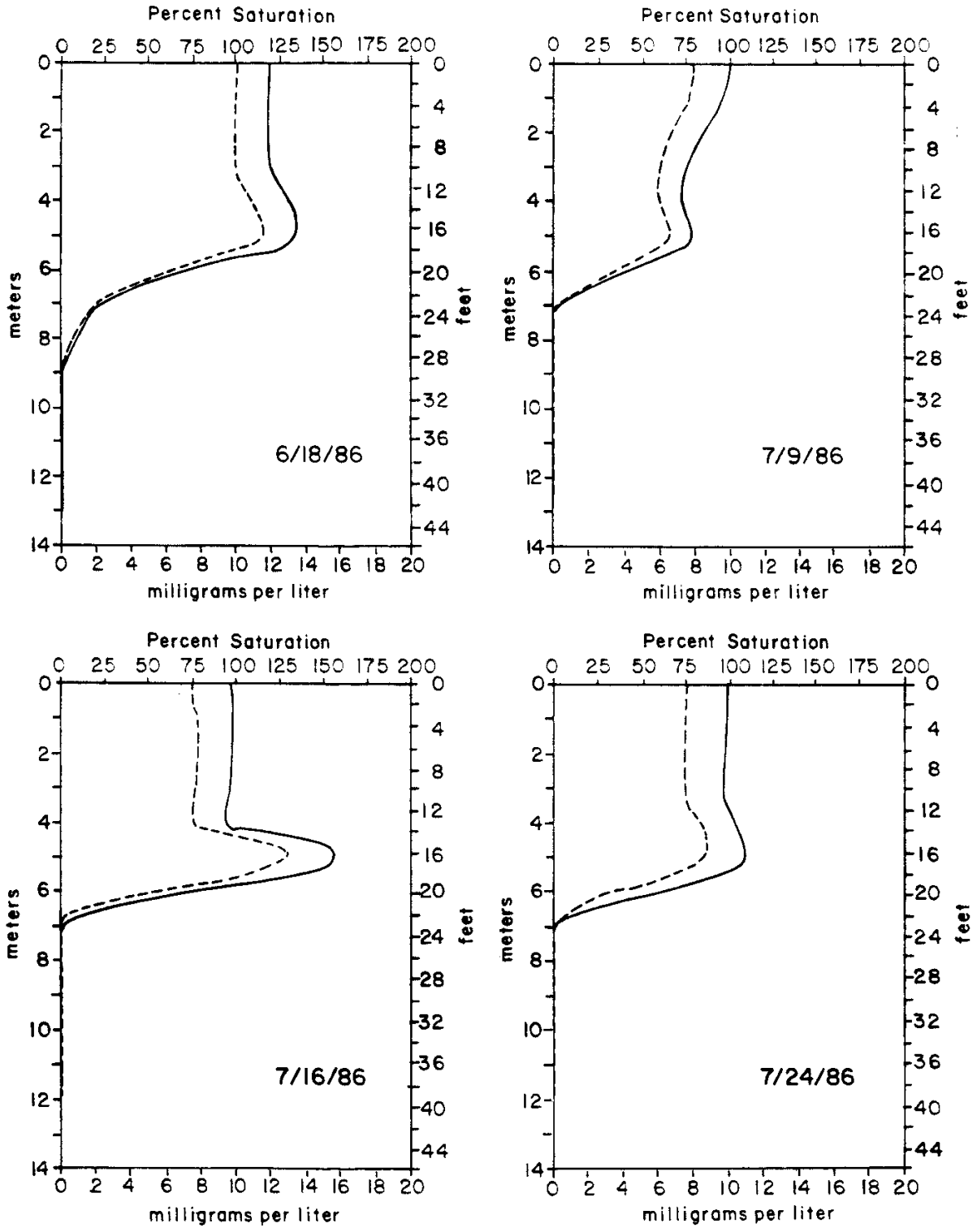
Appendix 2c. continued.



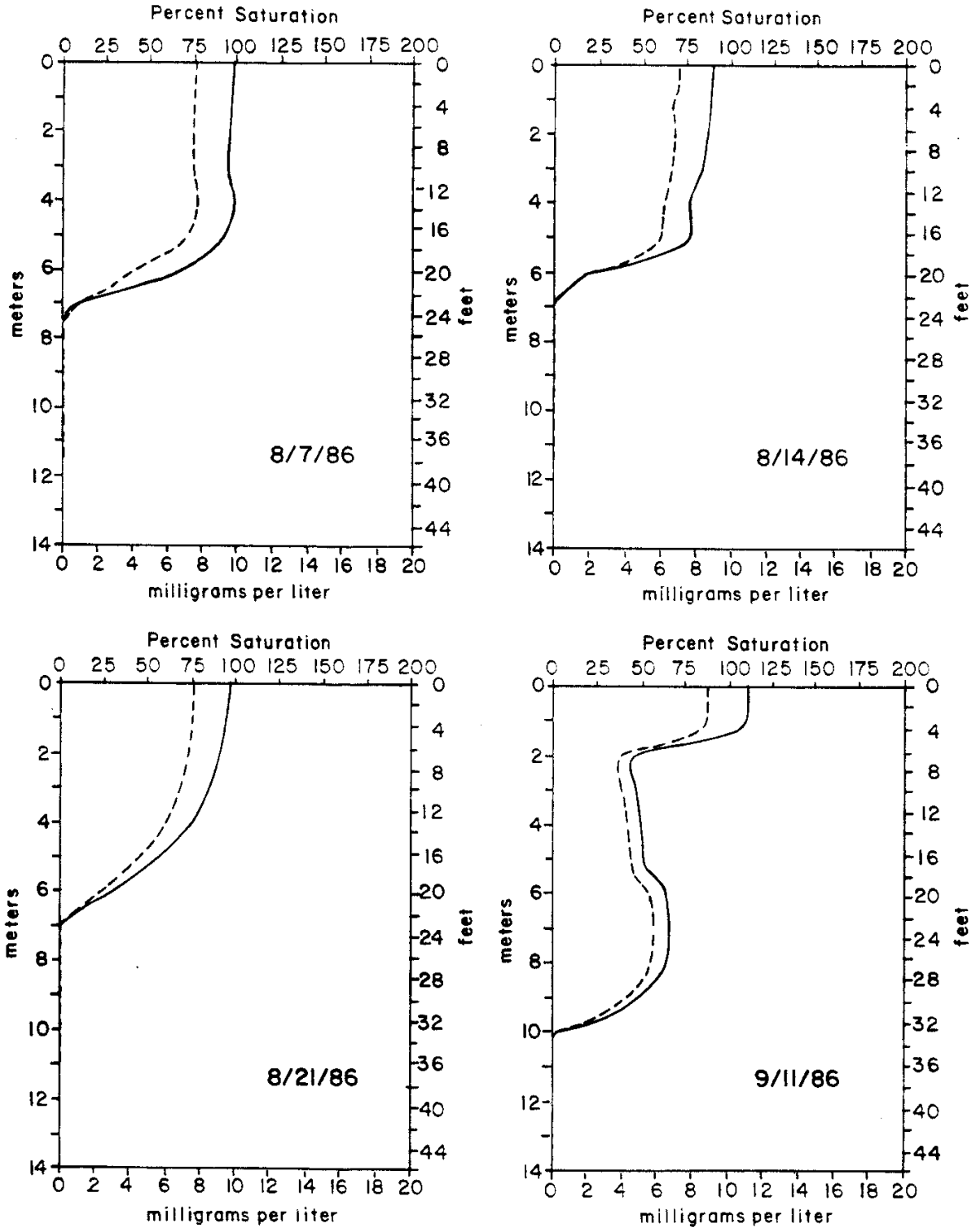
Appendix 2c. continued.



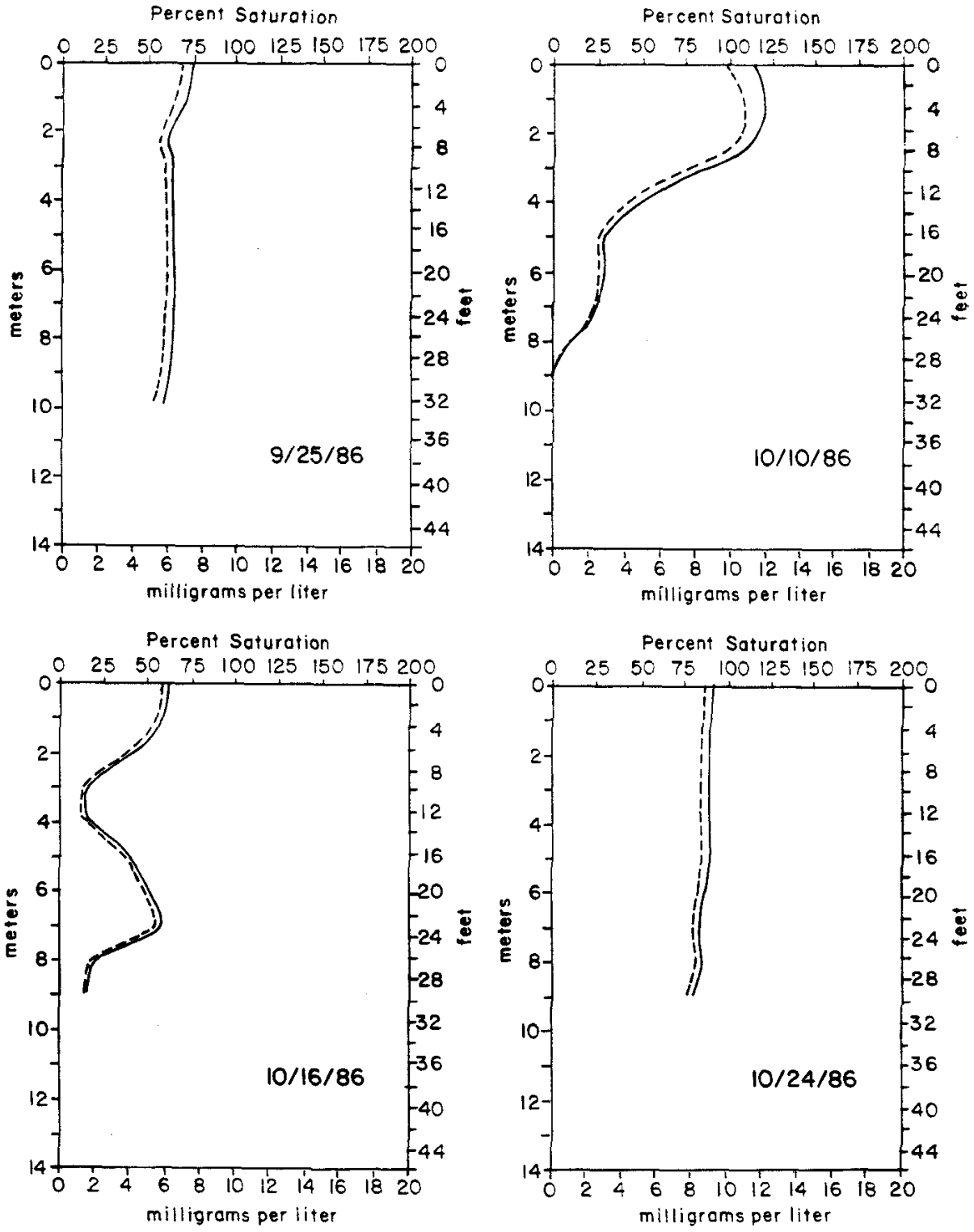
Appendix 3a. Dissolved oxygen in mg/l (– – –) and percent saturation (——) profiles for Morris Reservoir near the dam.



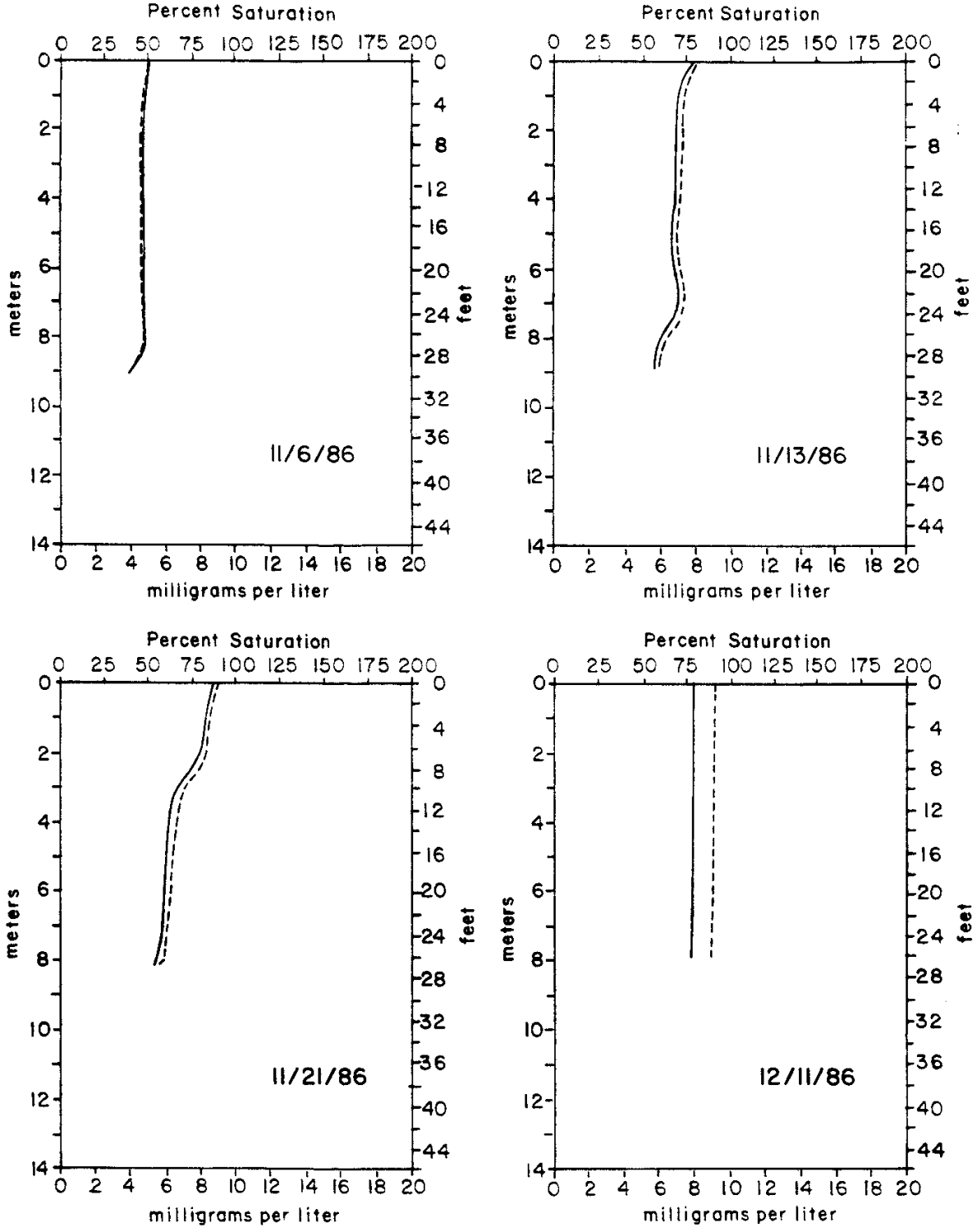
Appendix 3a. continued. mg/l (----) percent saturation (——)



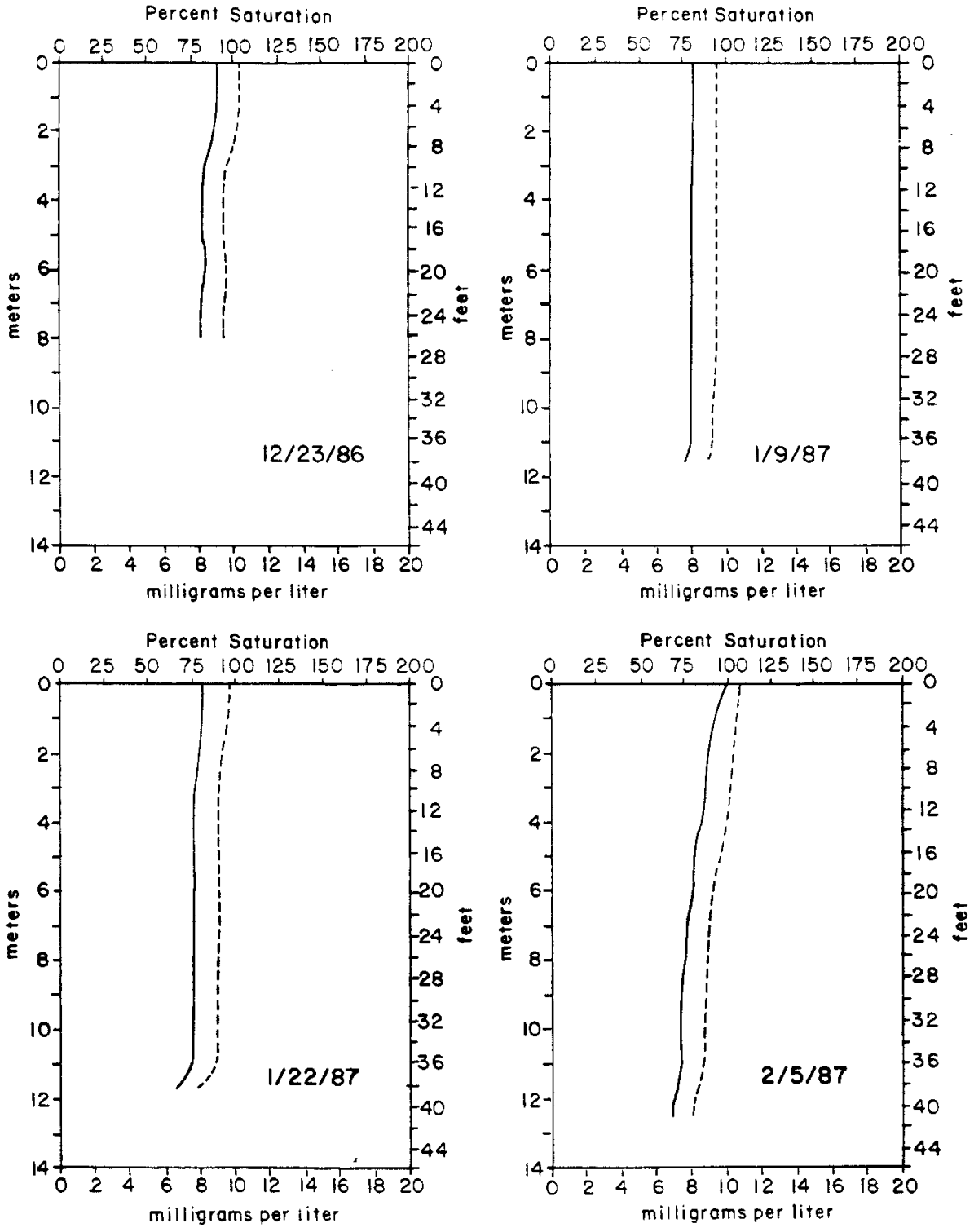
Appendix 3a. continued. mg/l (- - - -) percent saturation (——)



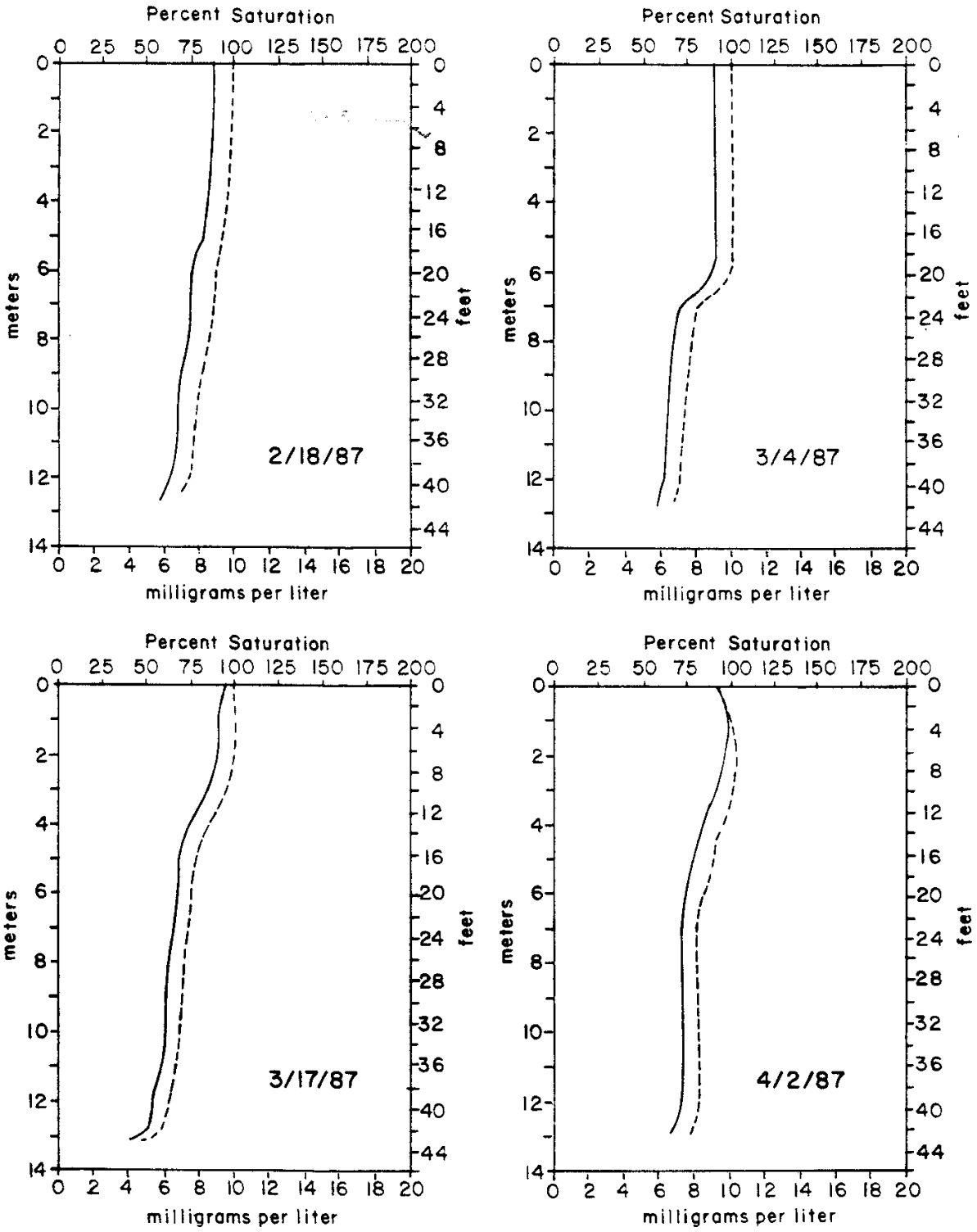
Appendix 3a. continued. mg/l(- - - -) percent saturation(——)



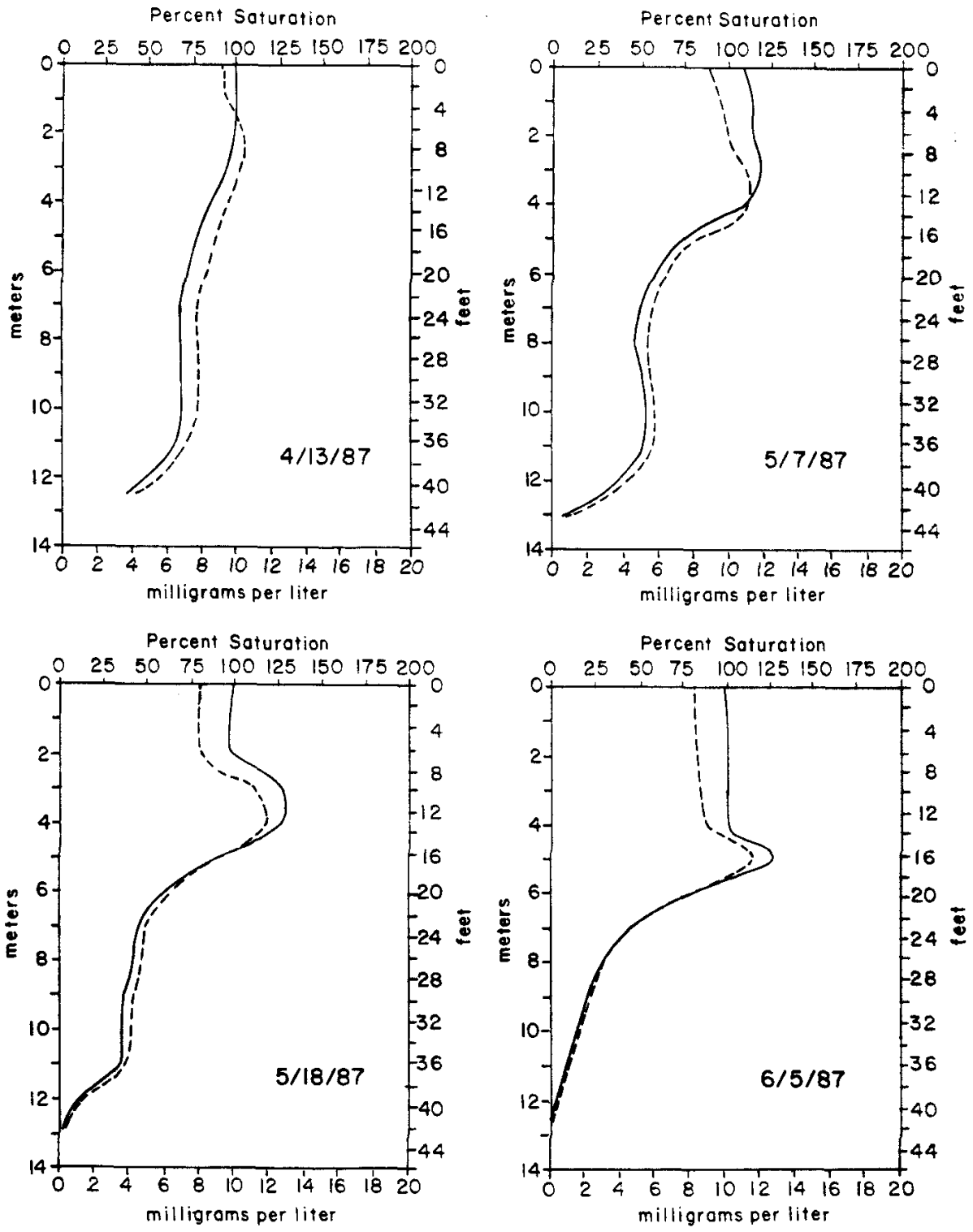
Appendix 3a. continued. mg/l (----) percent saturation (——)



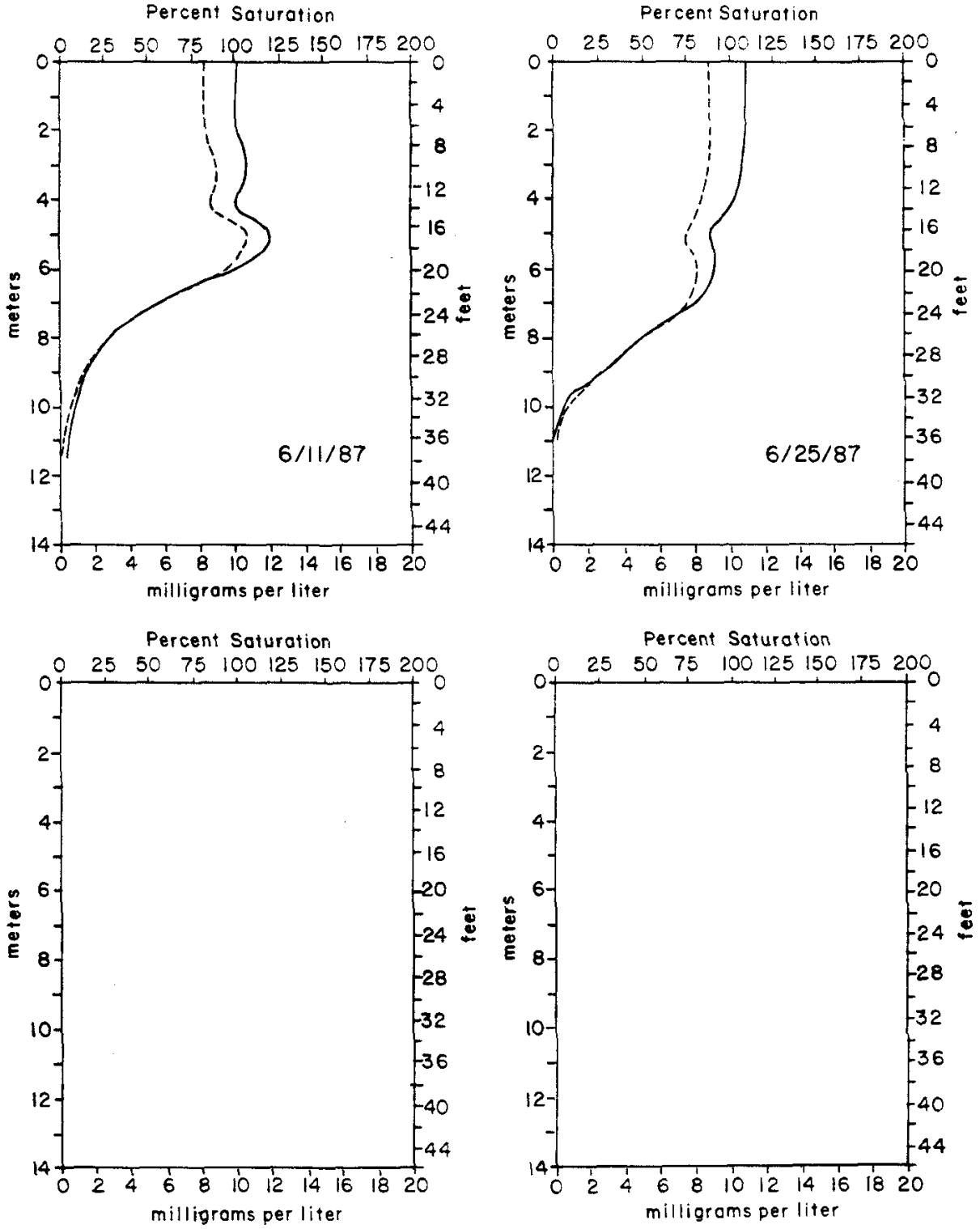
Appendix 3a. continued. mg/l (- - - -) percent saturation (——)



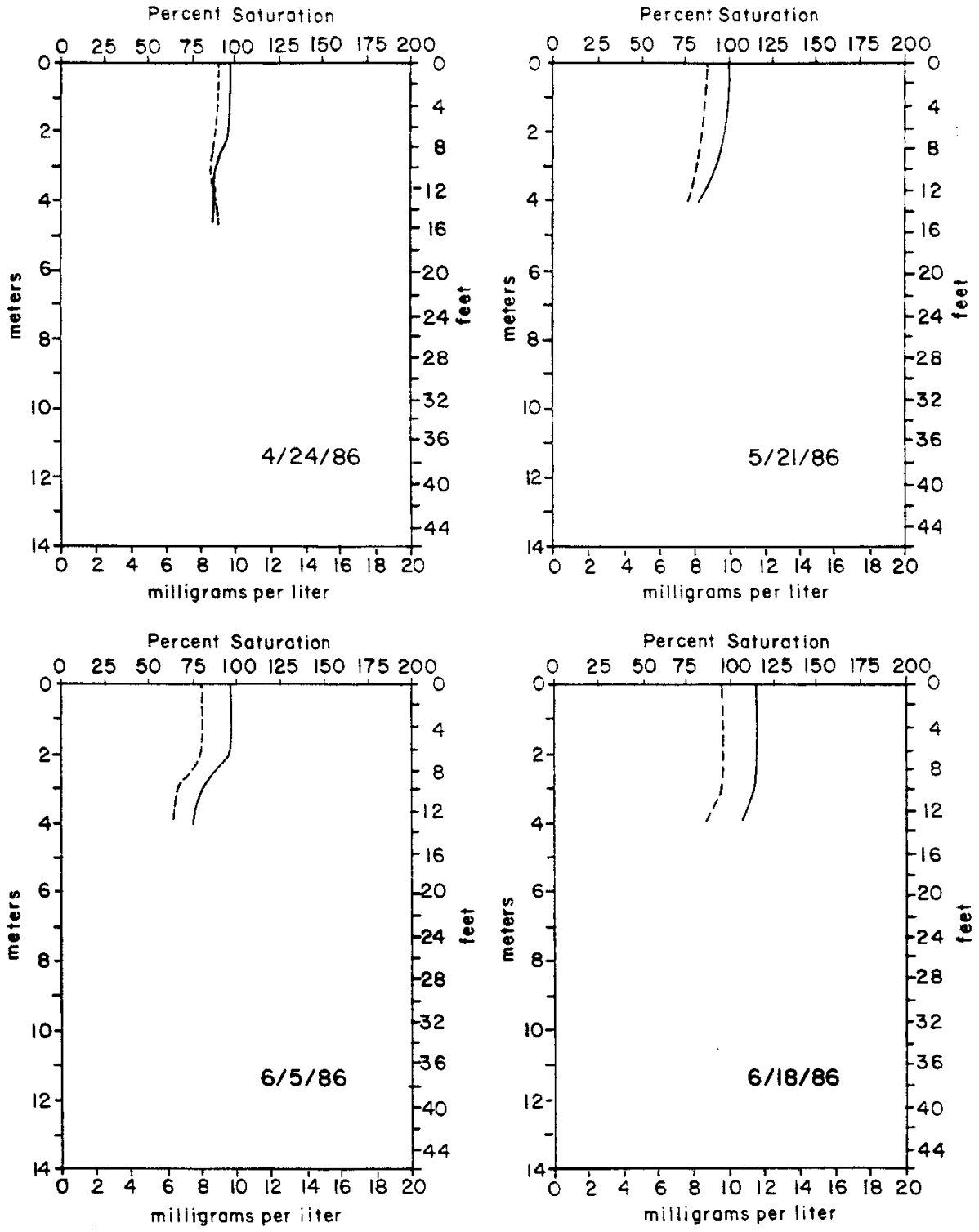
Appendix 3a. continued. mg/l (- - - -) percent saturation (———)



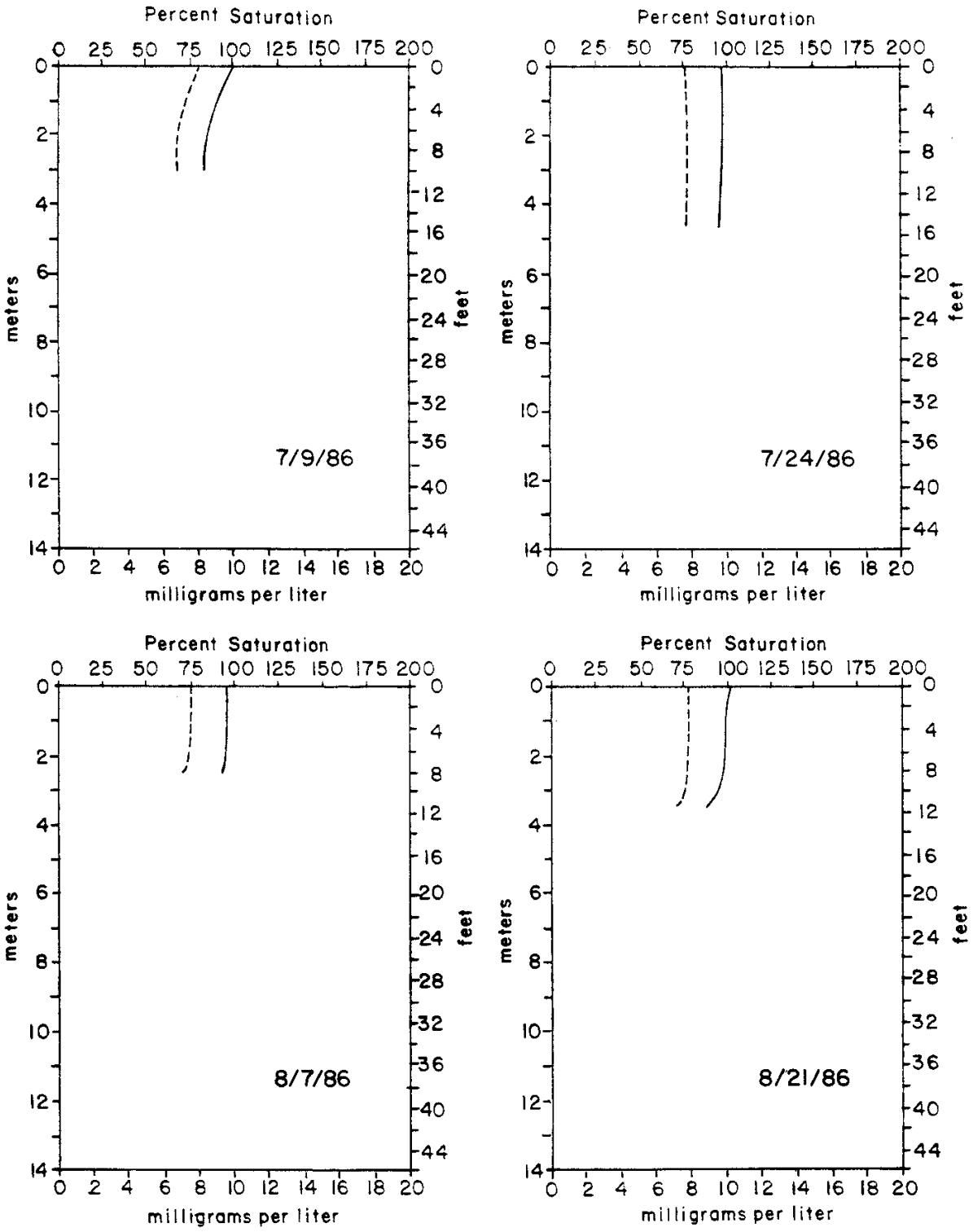
Appendix 3a. continued. mg/l (----) percent saturation (——)



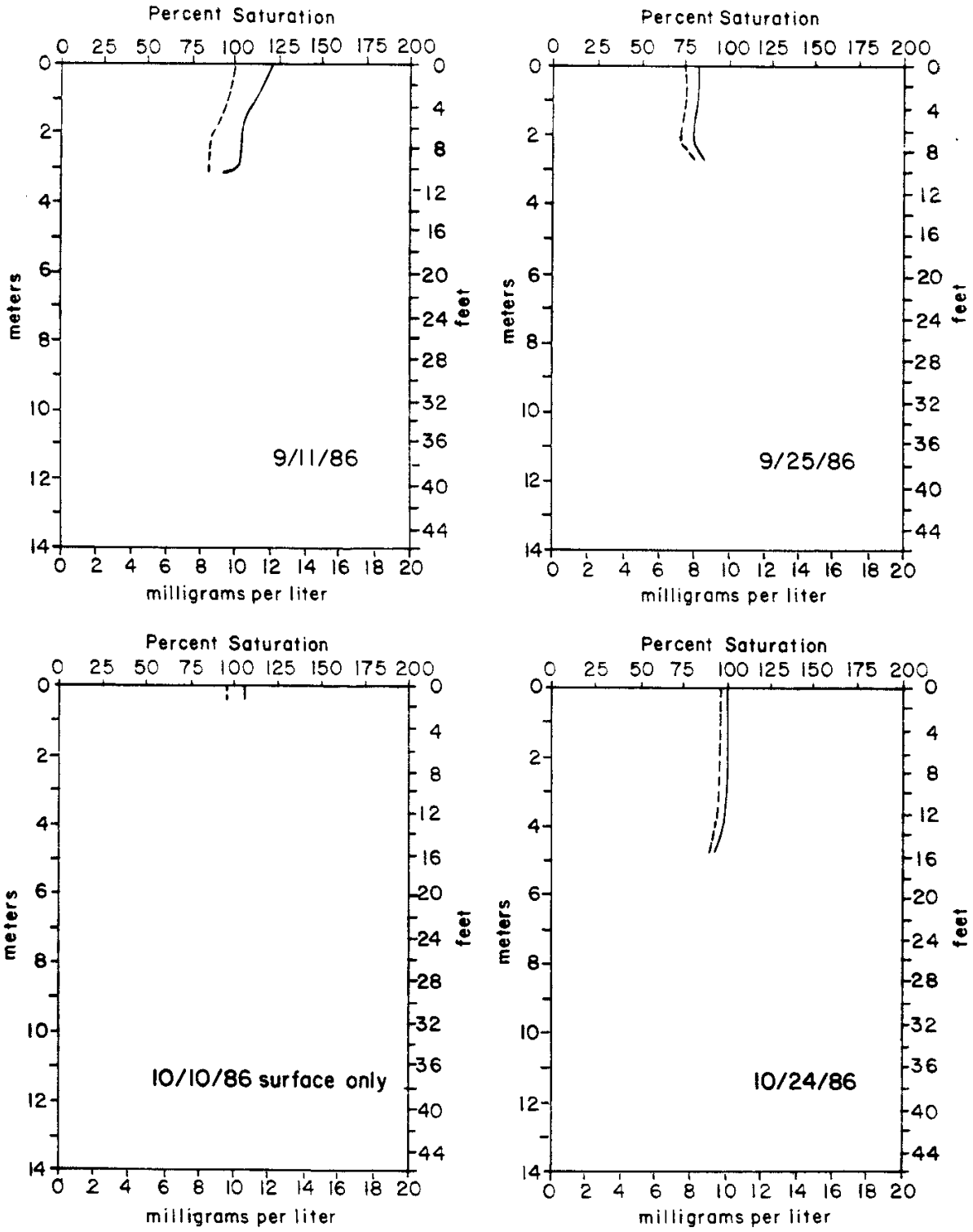
Appendix 3a. continued. mg/l(- - - -) percent saturation (——)



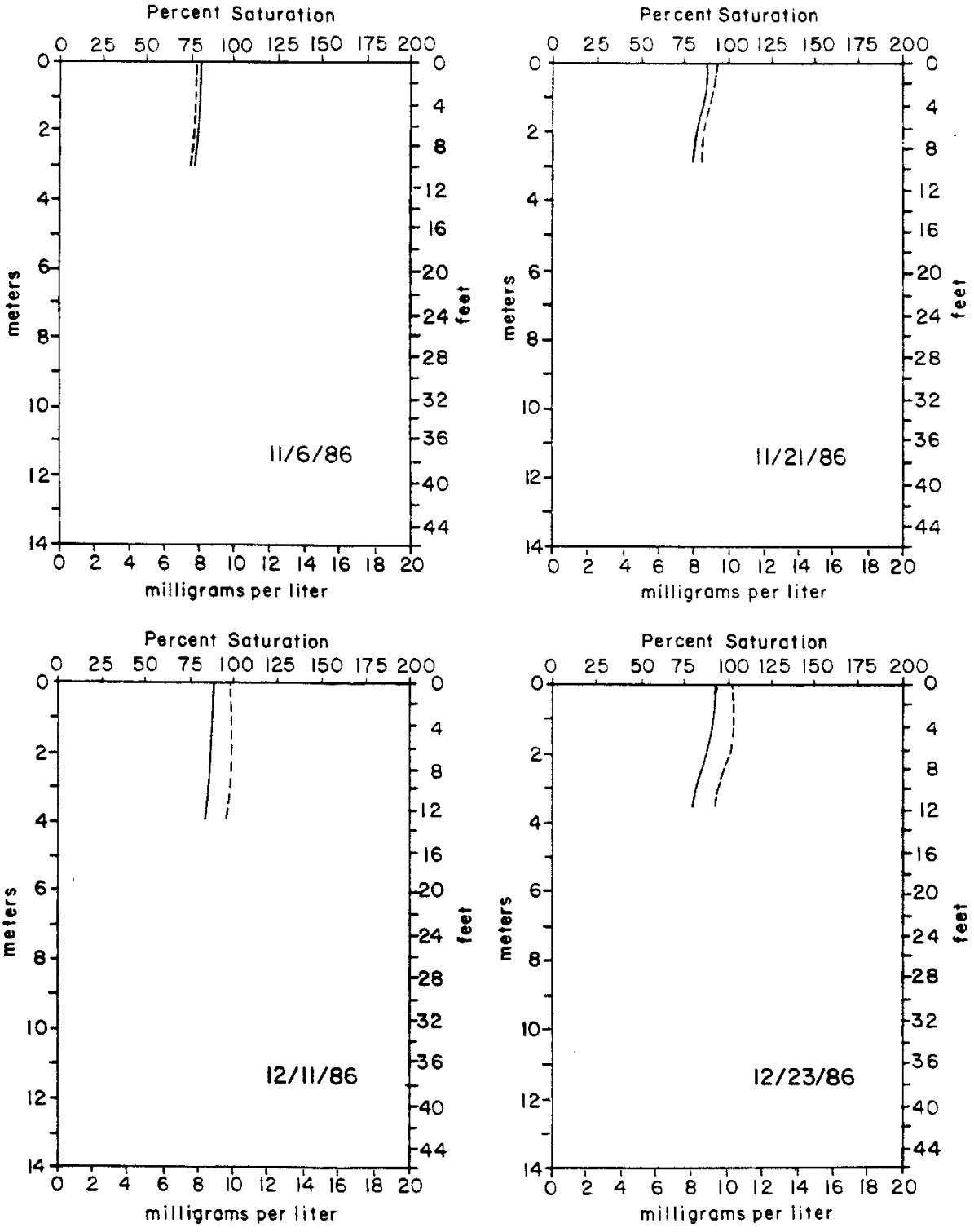
Appendix 3b. Dissolved oxygen in mg/l (- - - -) and percent saturation (——) profiles for Morris Reservoir in the Davis Creek arm.



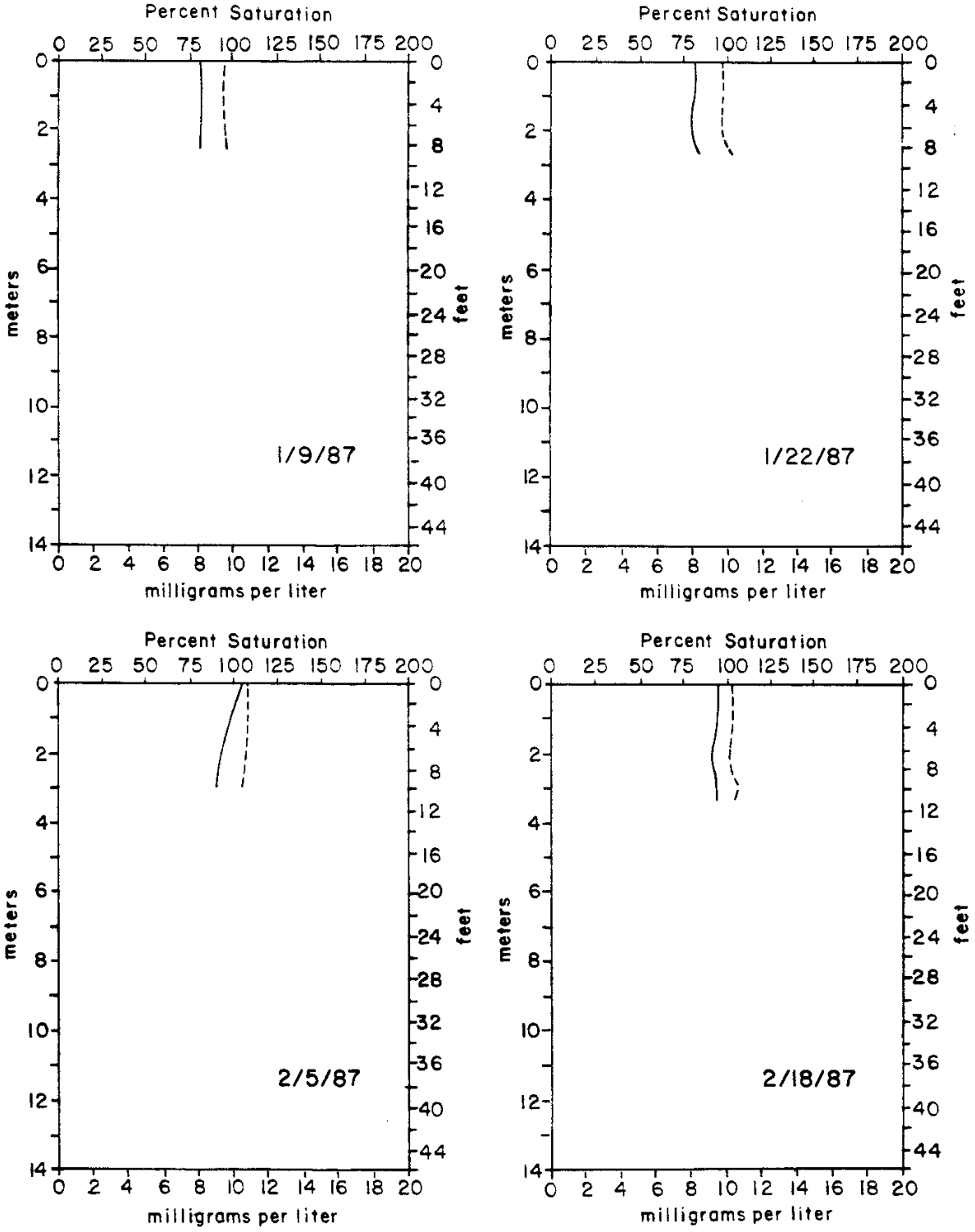
Appendix 3b. continued. mg/l (- - - -) percent saturation (——)



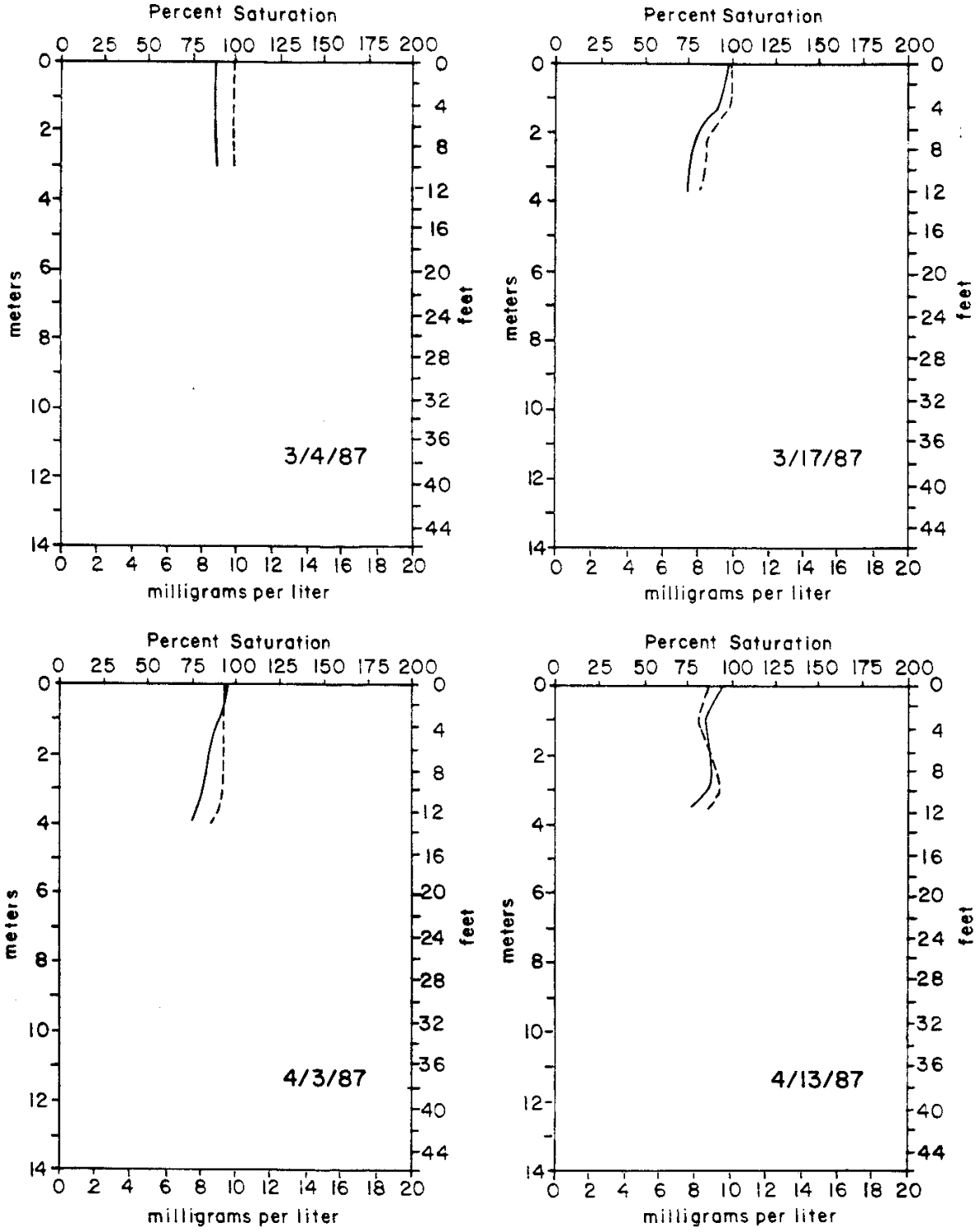
Appendix 3b. continued. mg/l (----) percent saturation (——)



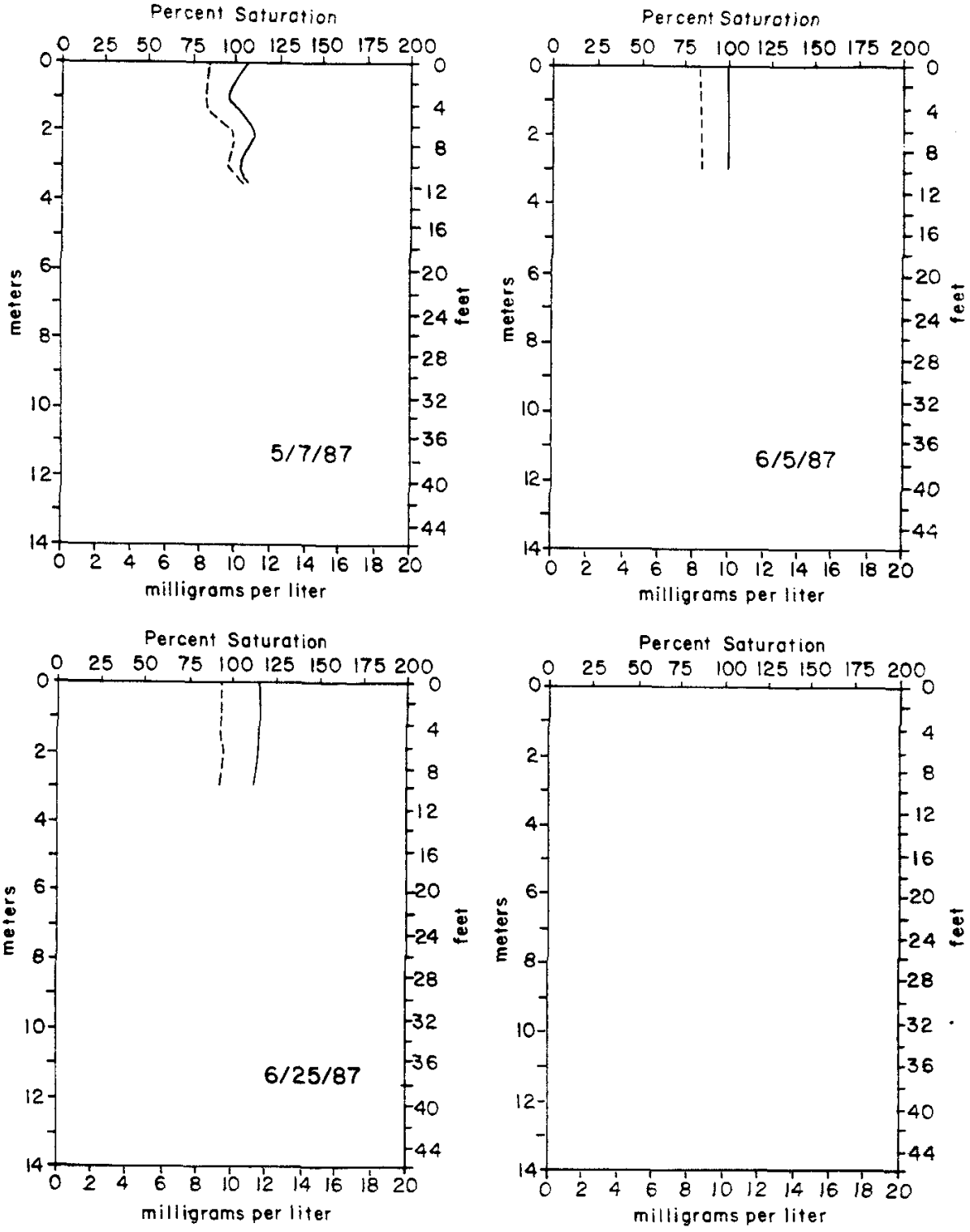
Appendix 3b. continued. mg/l (----) percent saturation (——)



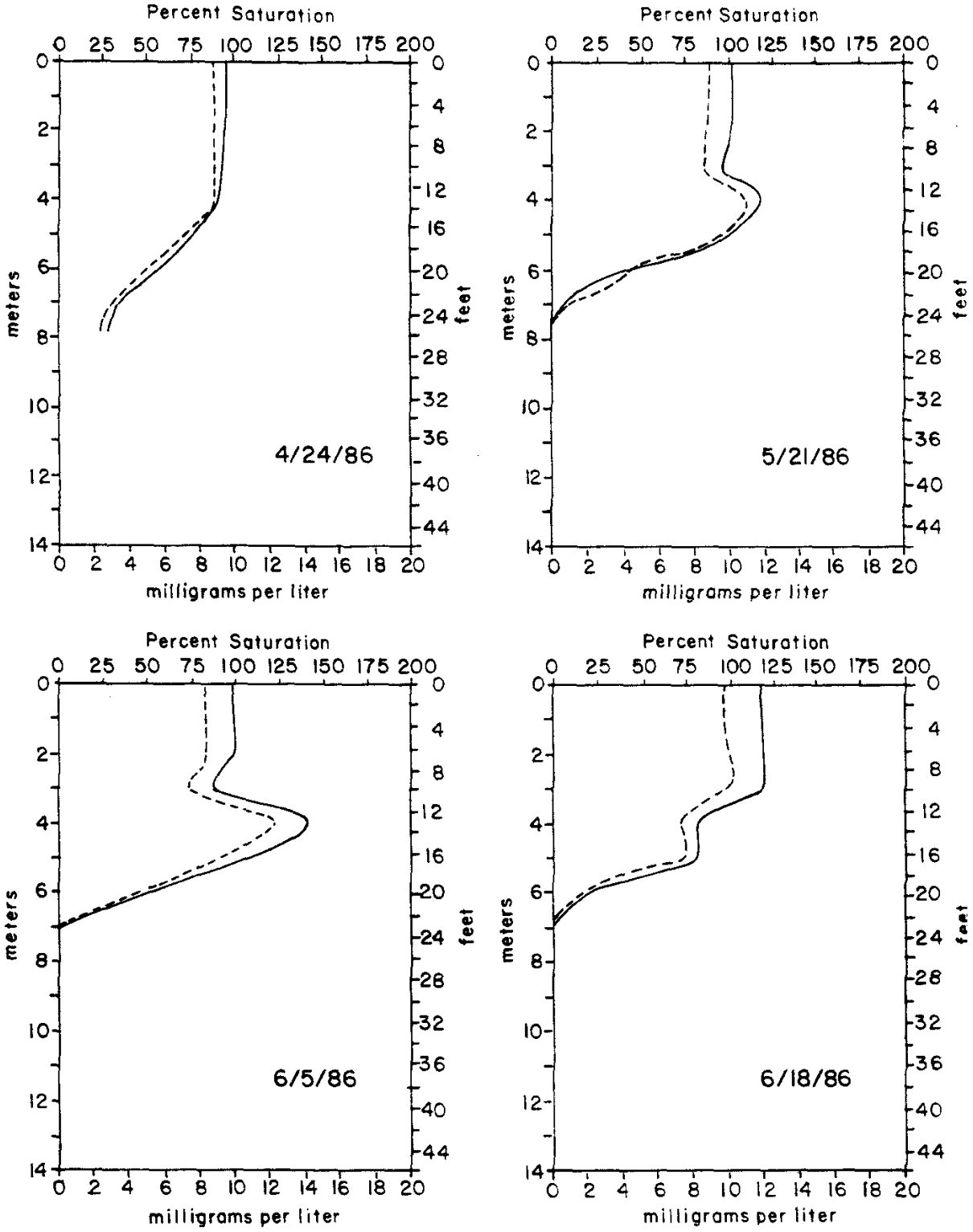
Appendix 3b. continued. mg/l (- - - -) percent saturation (———)



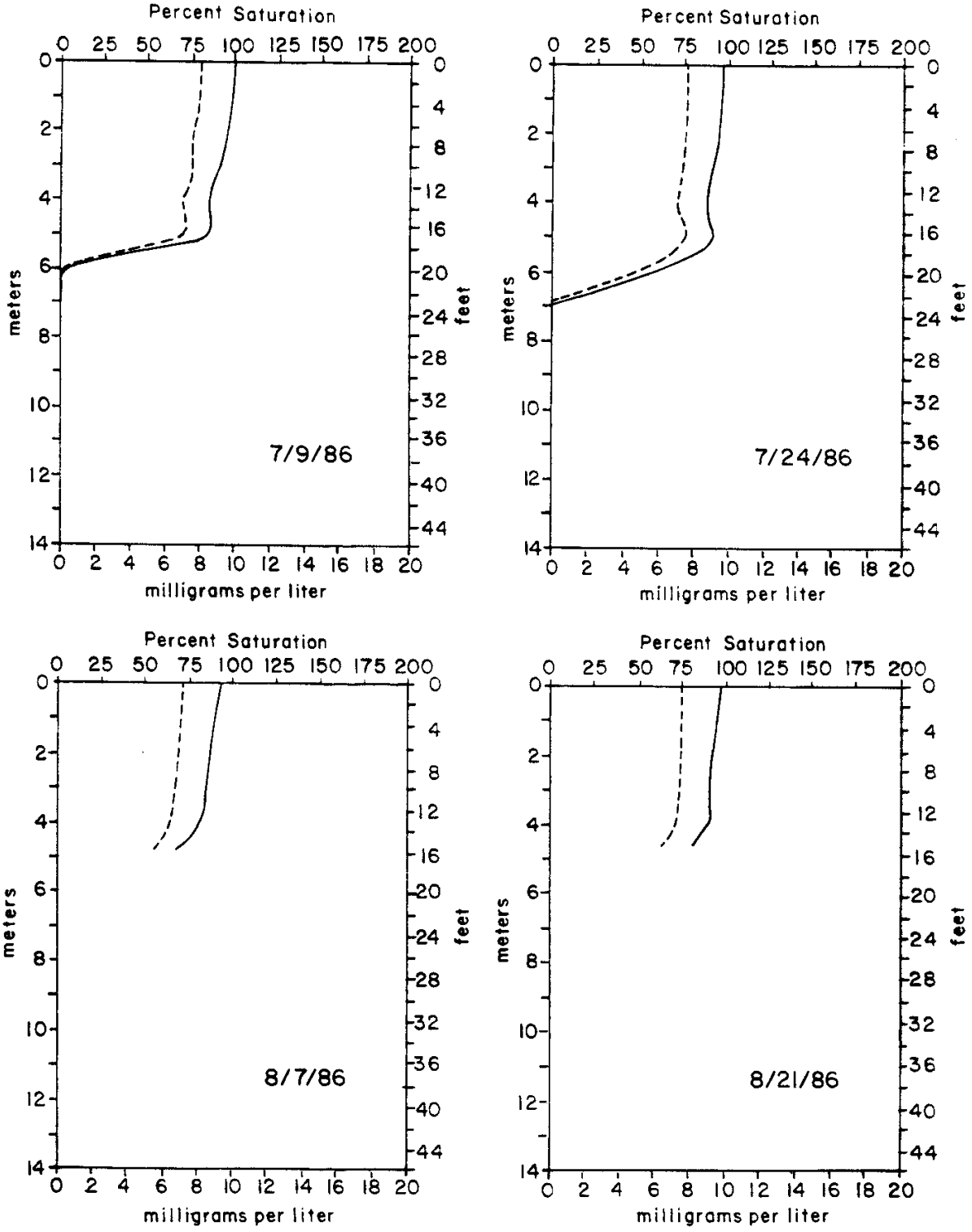
Appendix 36. continued. mg/l (- - - -) percent saturation (———)



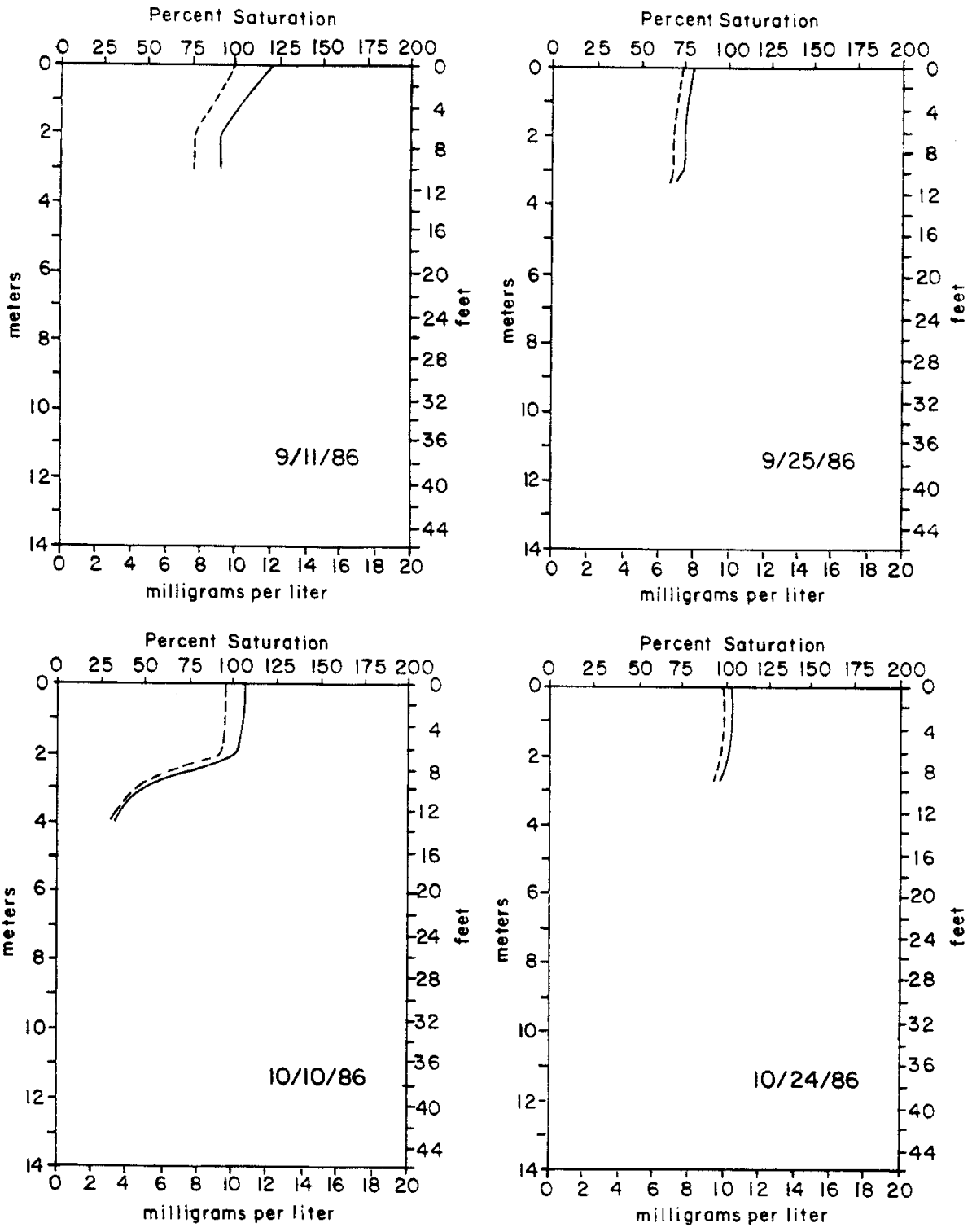
Appendix 3b. continued. mg/l (- - - -) percent saturation (——)



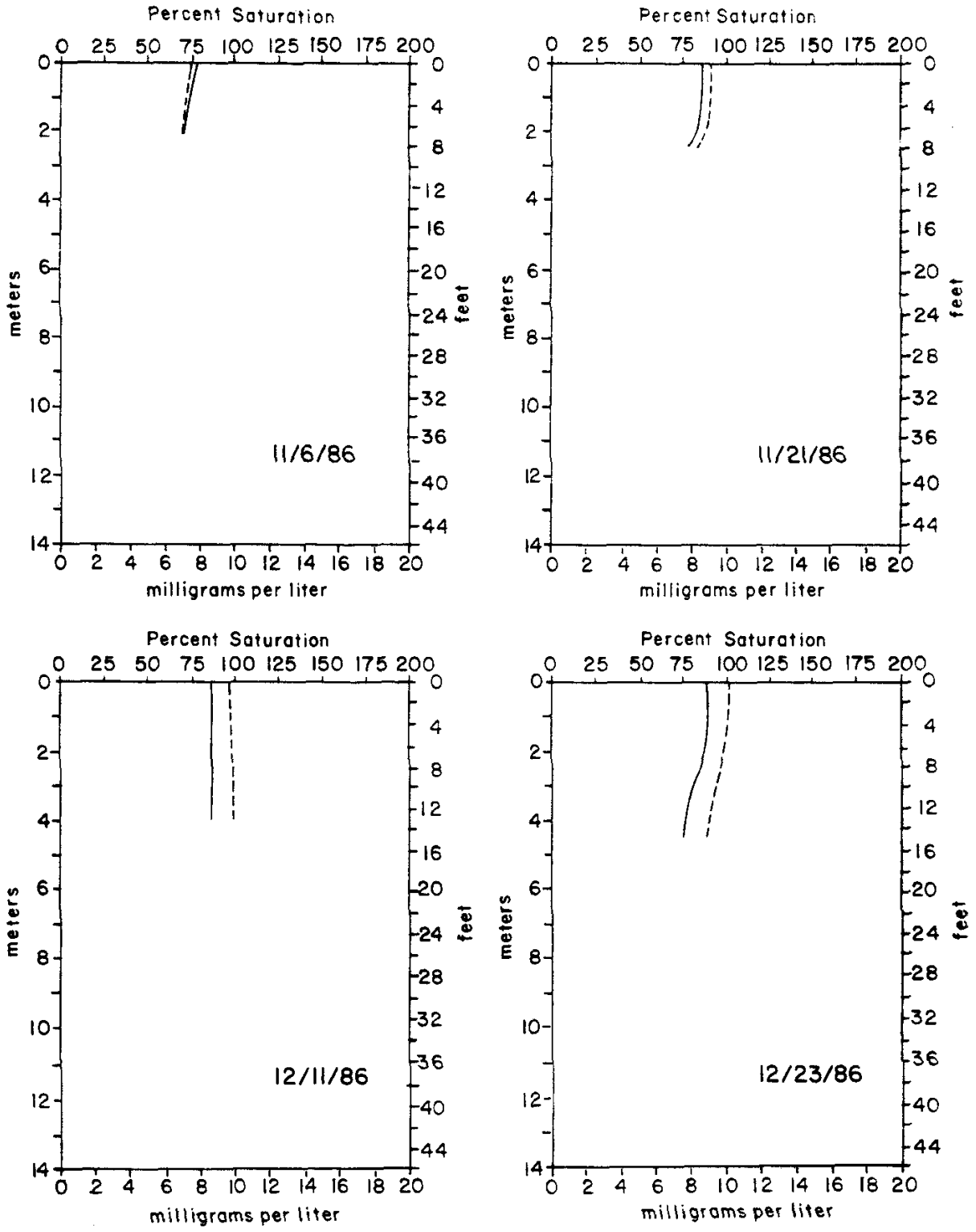
Appendix 3c. Dissolved oxygen in mg/l(----) and percent saturation(——) profiles for Morris Reservoir in the east arm.



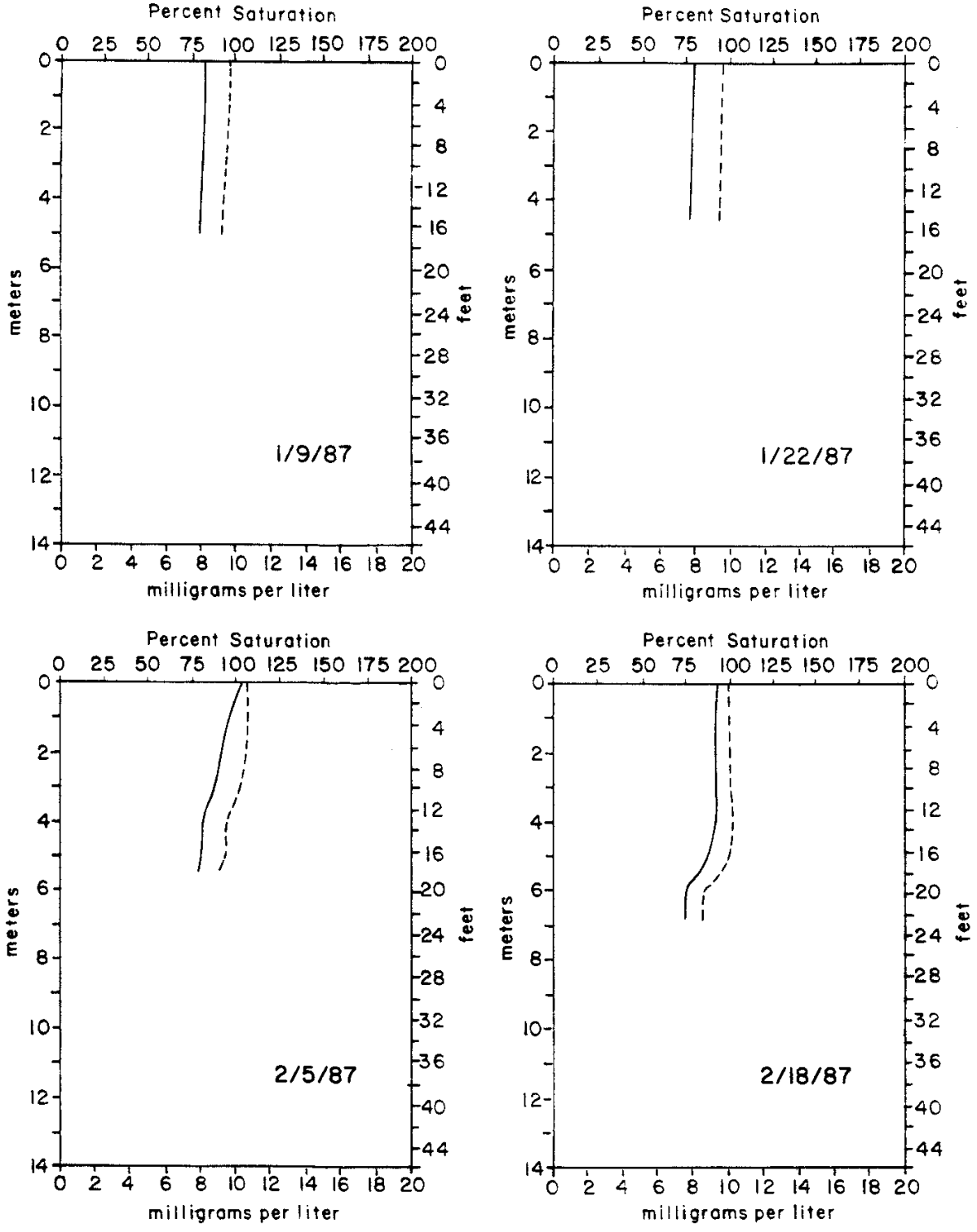
Appendix 3c. continued. mg/l(- - - -) percent saturation (——)



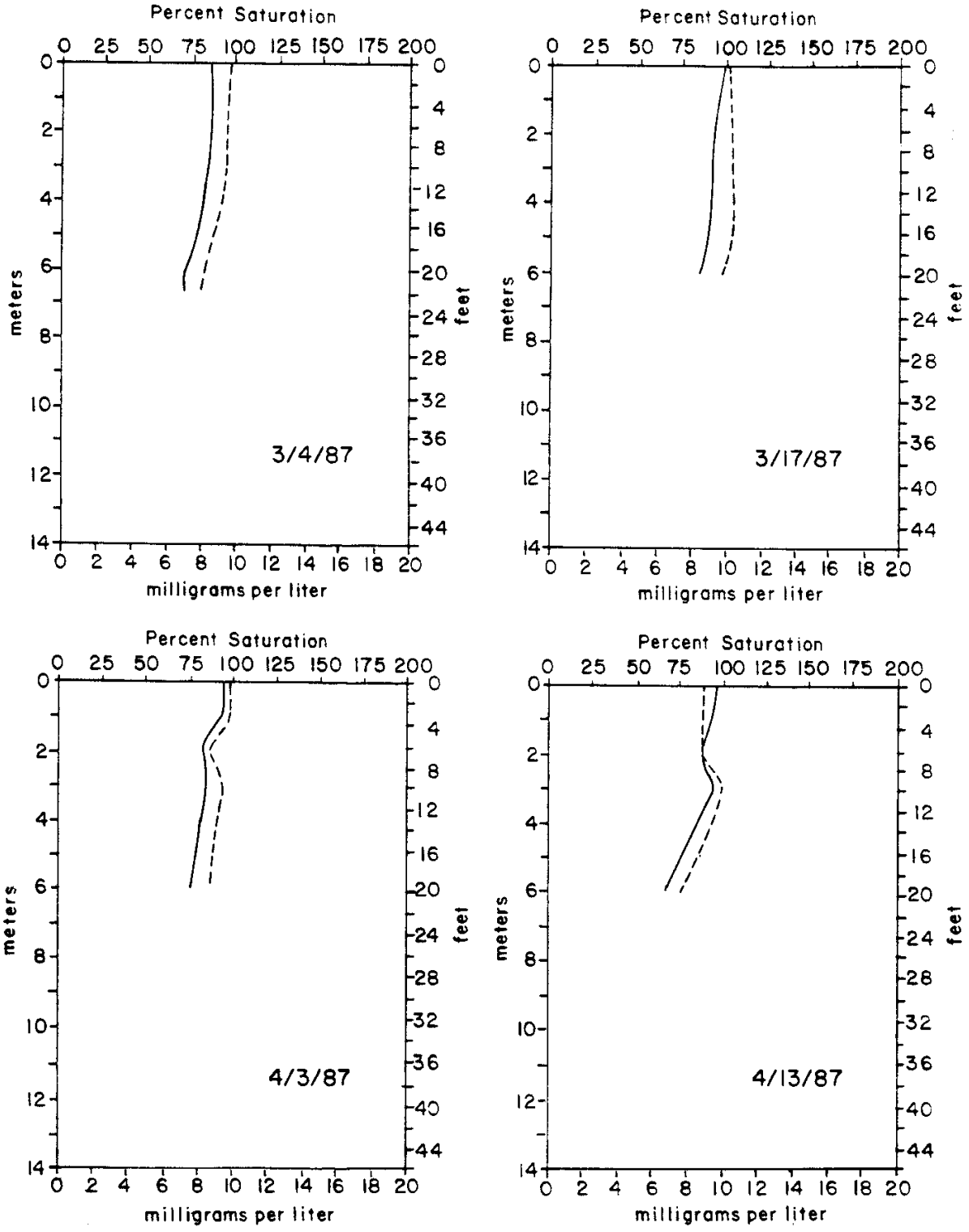
Appendix 3c. continued. mg/l (----) percent saturation (——)



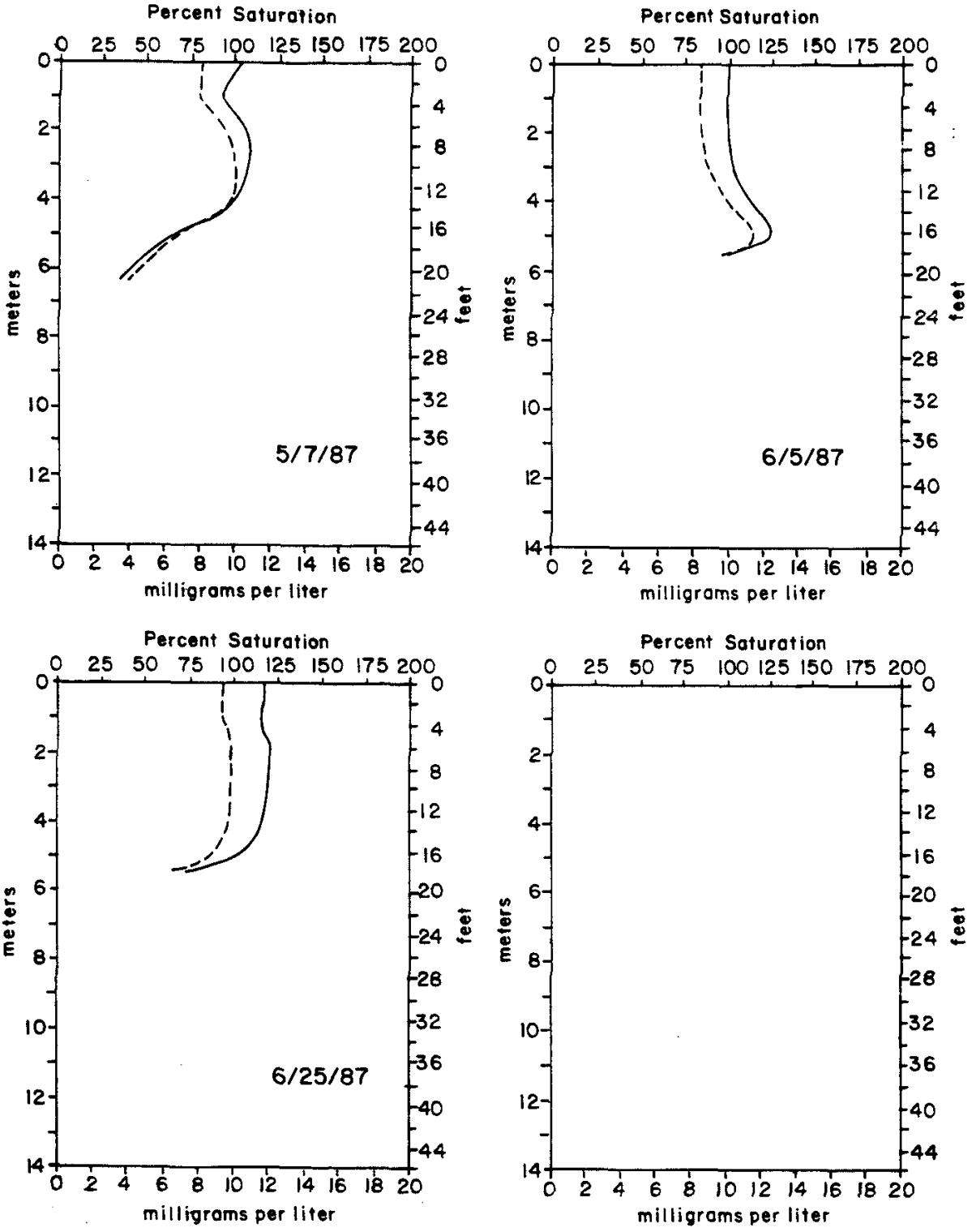
Appendix 3c. continued. mg/l (- - - -) percent saturation (——)



Appendix 3c. continued. mg/l(- - - -) percent saturation(——)

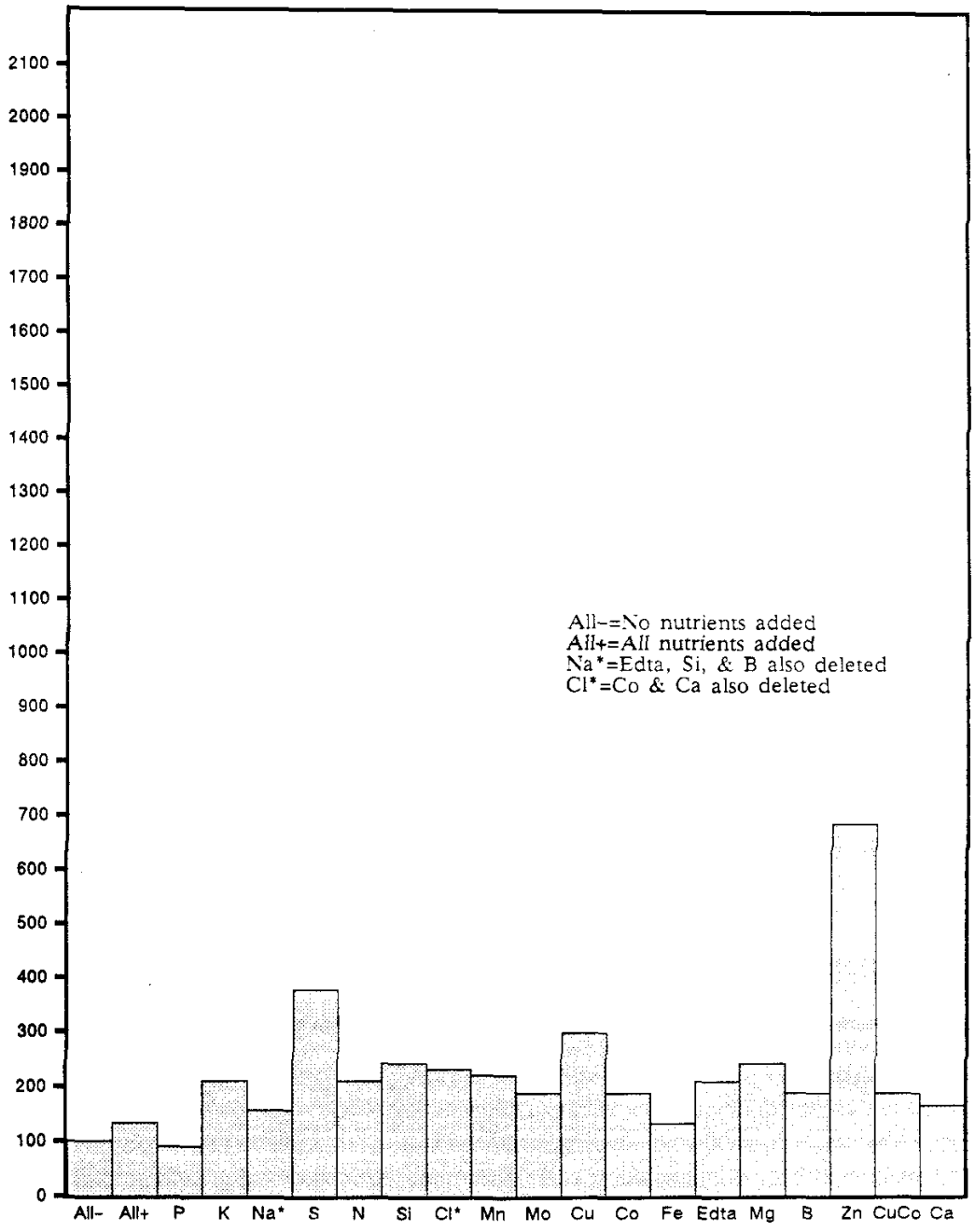


Appendix 3c. continued. mg/l (- - - -) percent saturation (——)

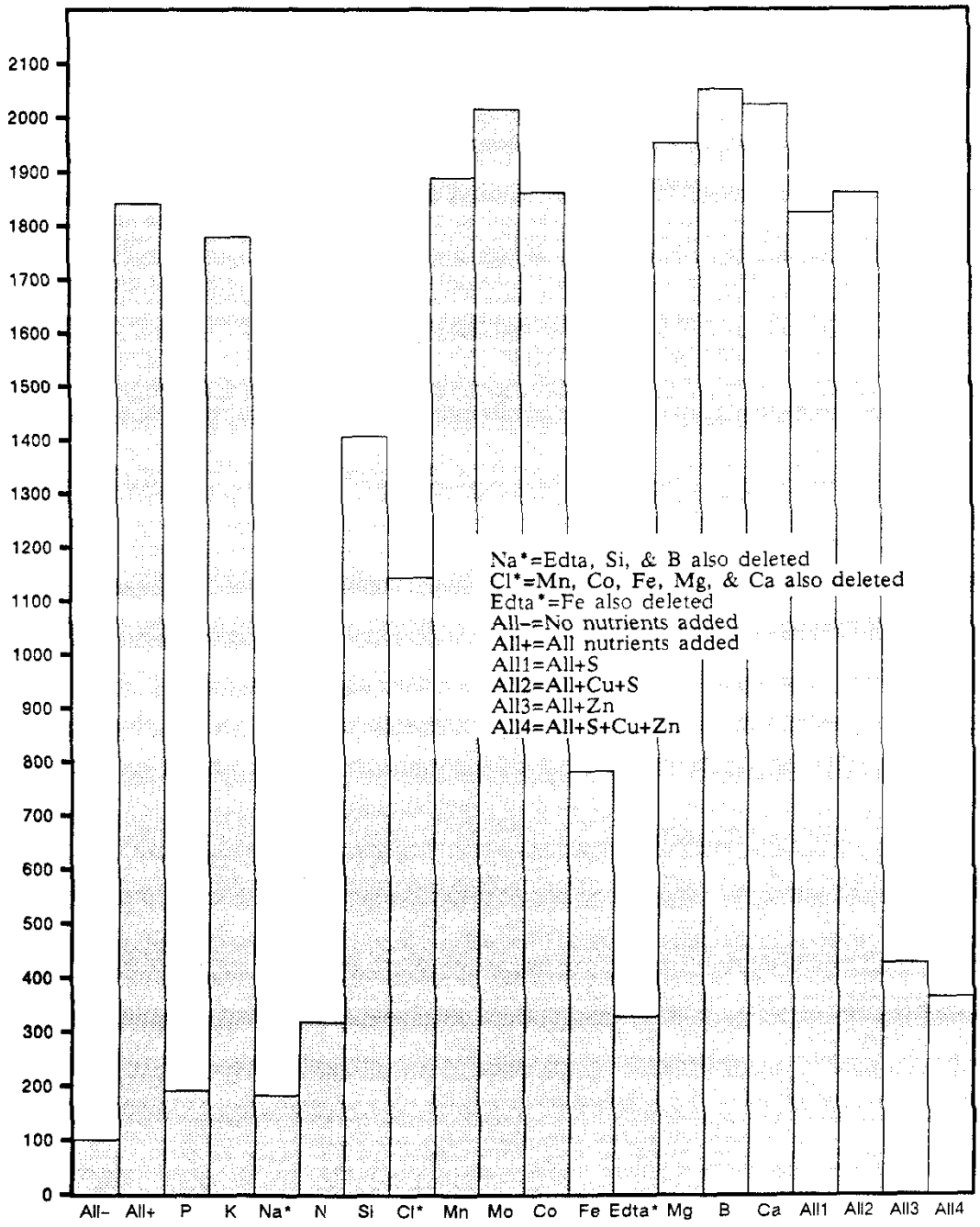


Appendix 3c. continued. mg/l (- - - -) percent saturation (———)

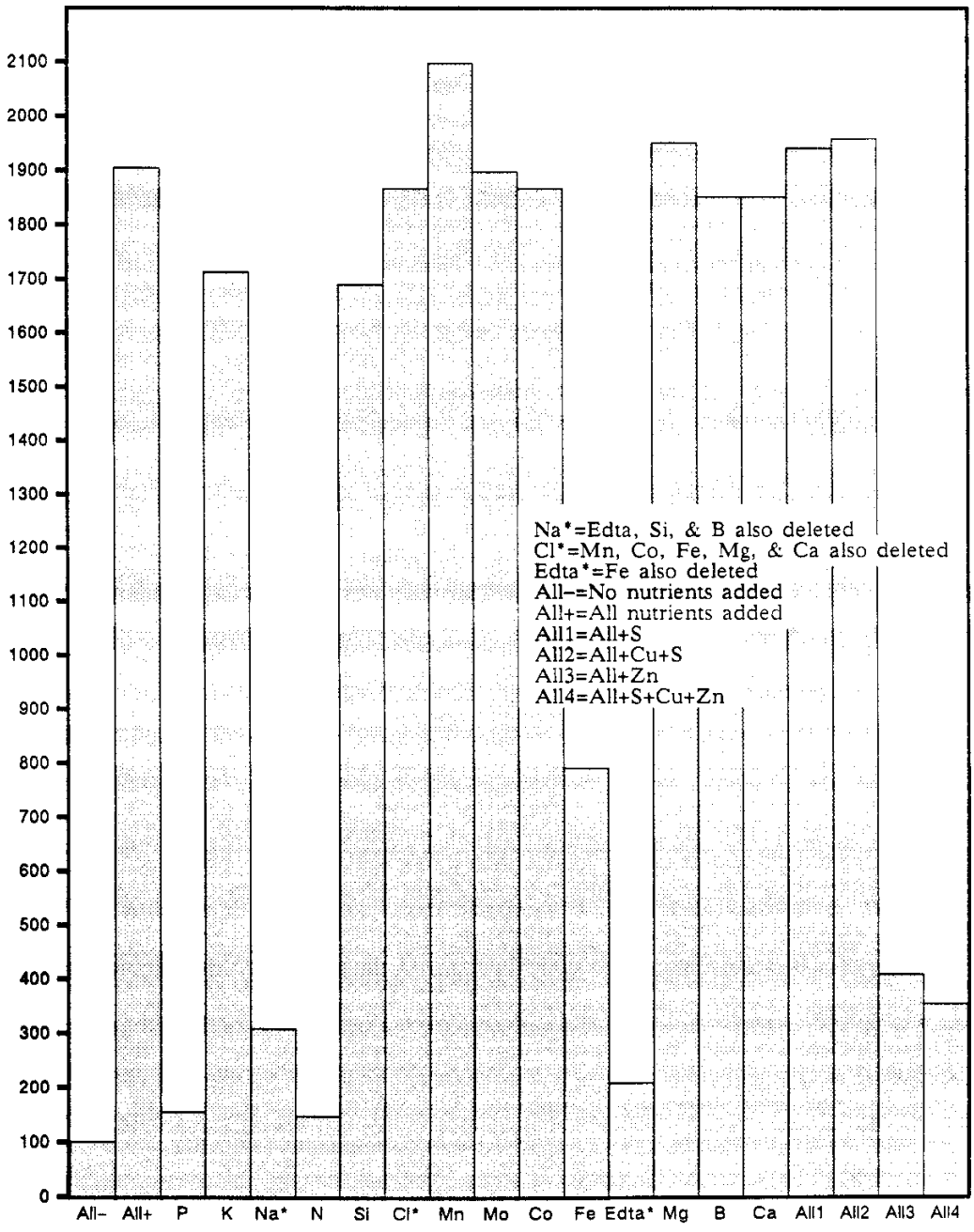
Appendix 4a. Algal growth (as percentage of control with no added nutrients) for various nutrients deleted from bioassay bottles during June 1986.



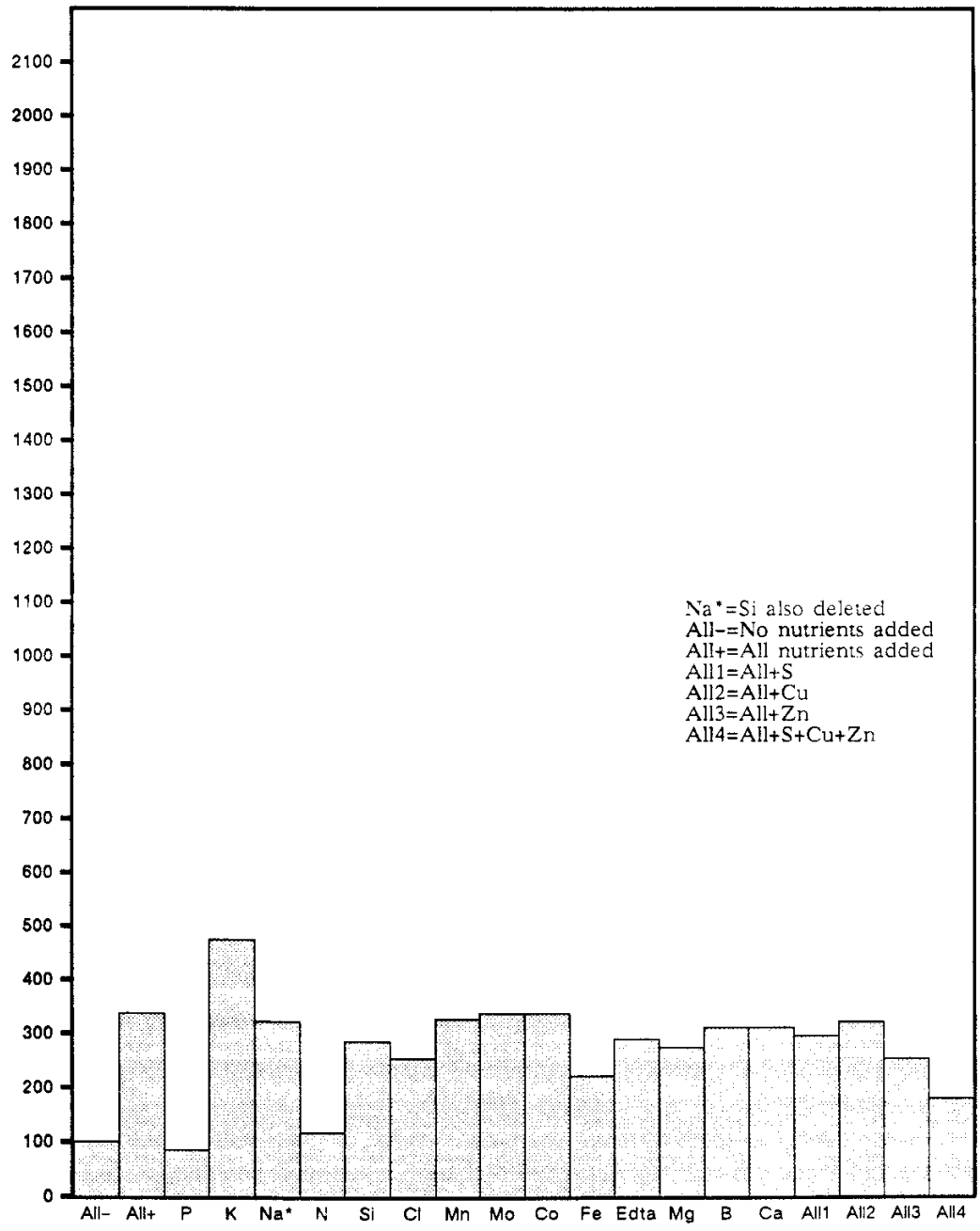
Appendix 4b. Algal growth (as percentage of control with no added nutrients) for various nutrients deleted from bioassay bottles during July 1986.



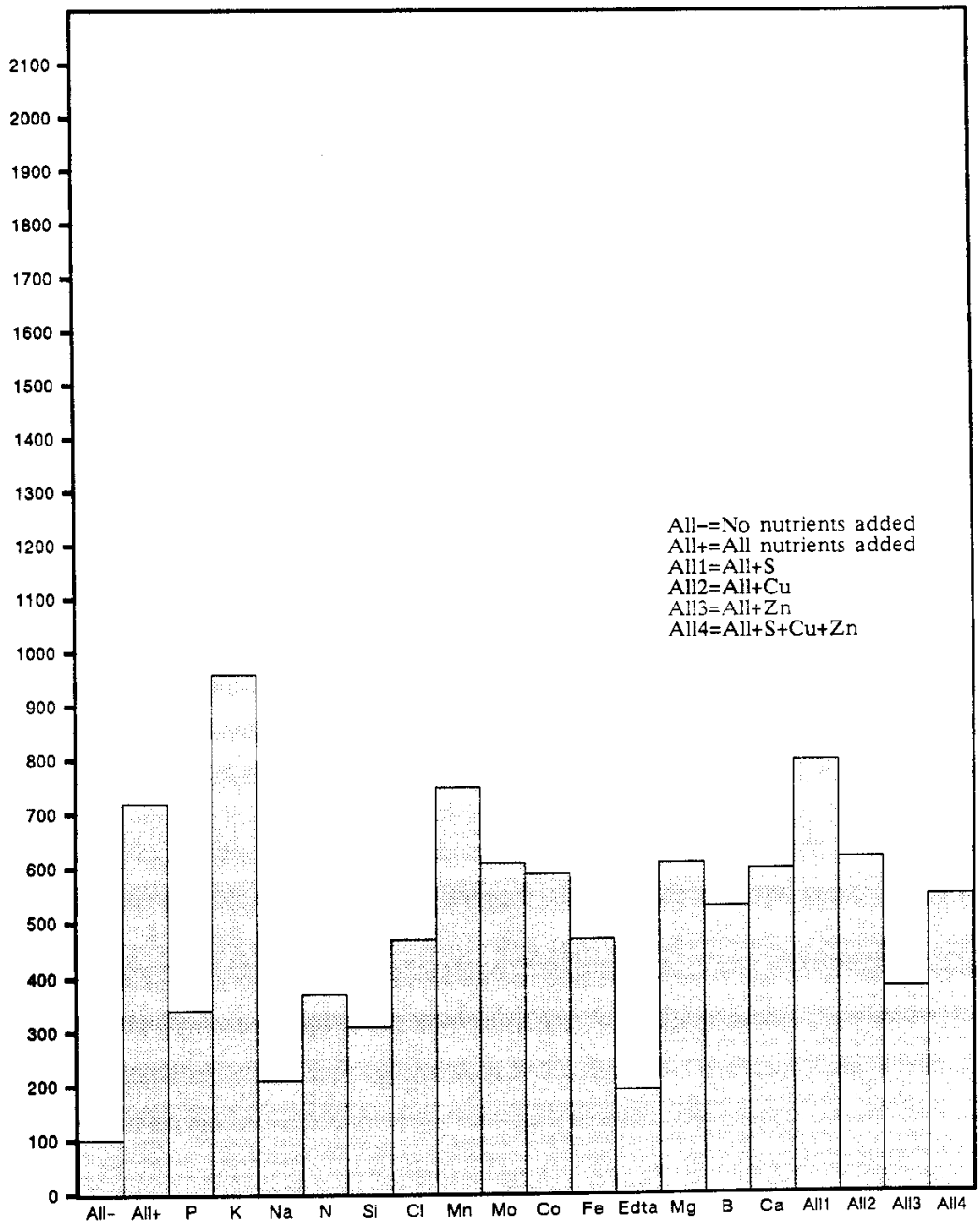
Appendix 4c. Algal growth (as percentage of control with no added nutrients) for various nutrients deleted from bioassay bottles during August 1986.



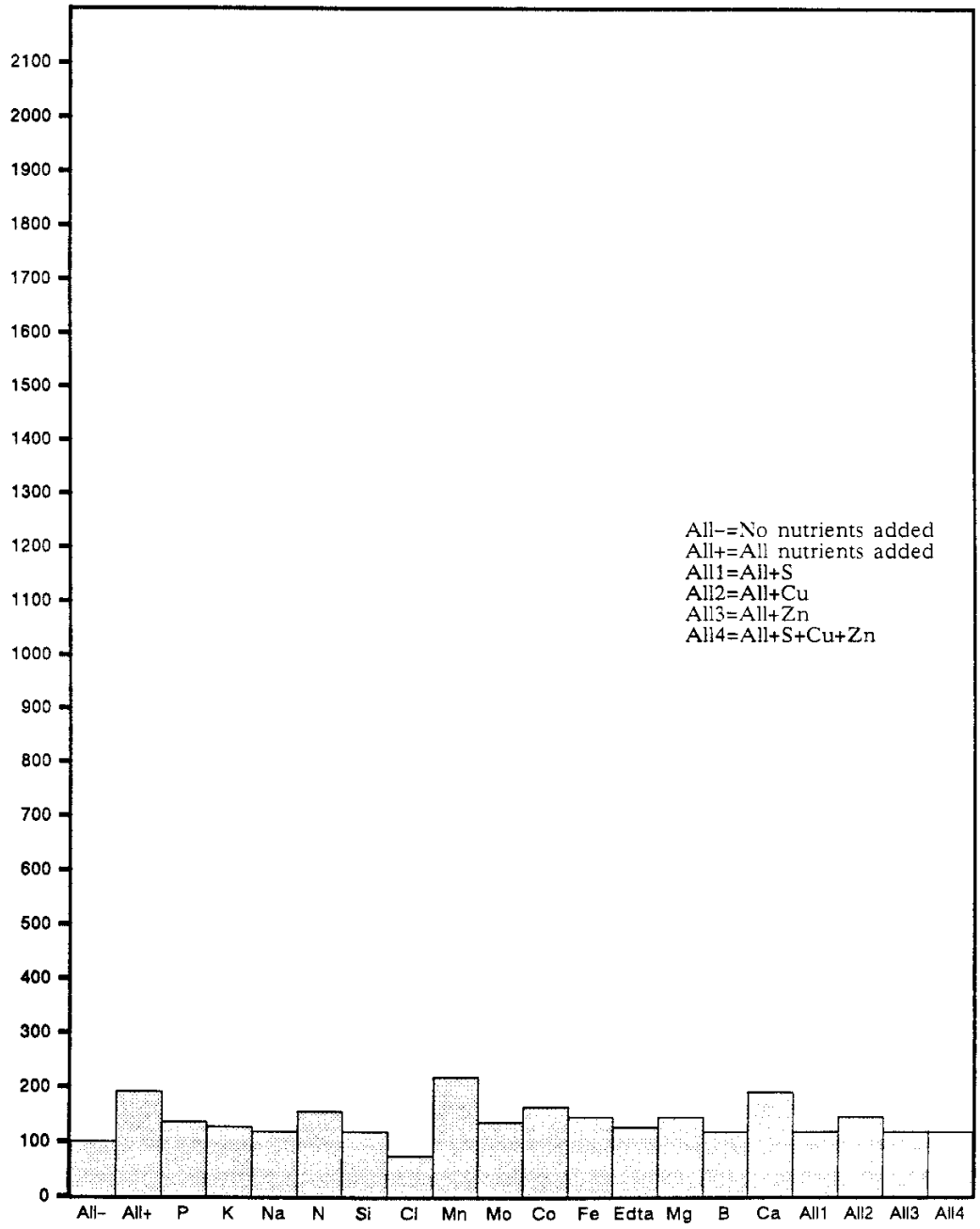
Appendix 4d. Algal growth (as percentage of control with no added nutrients) for various nutrients deleted from bioassay bottles during September 1986.



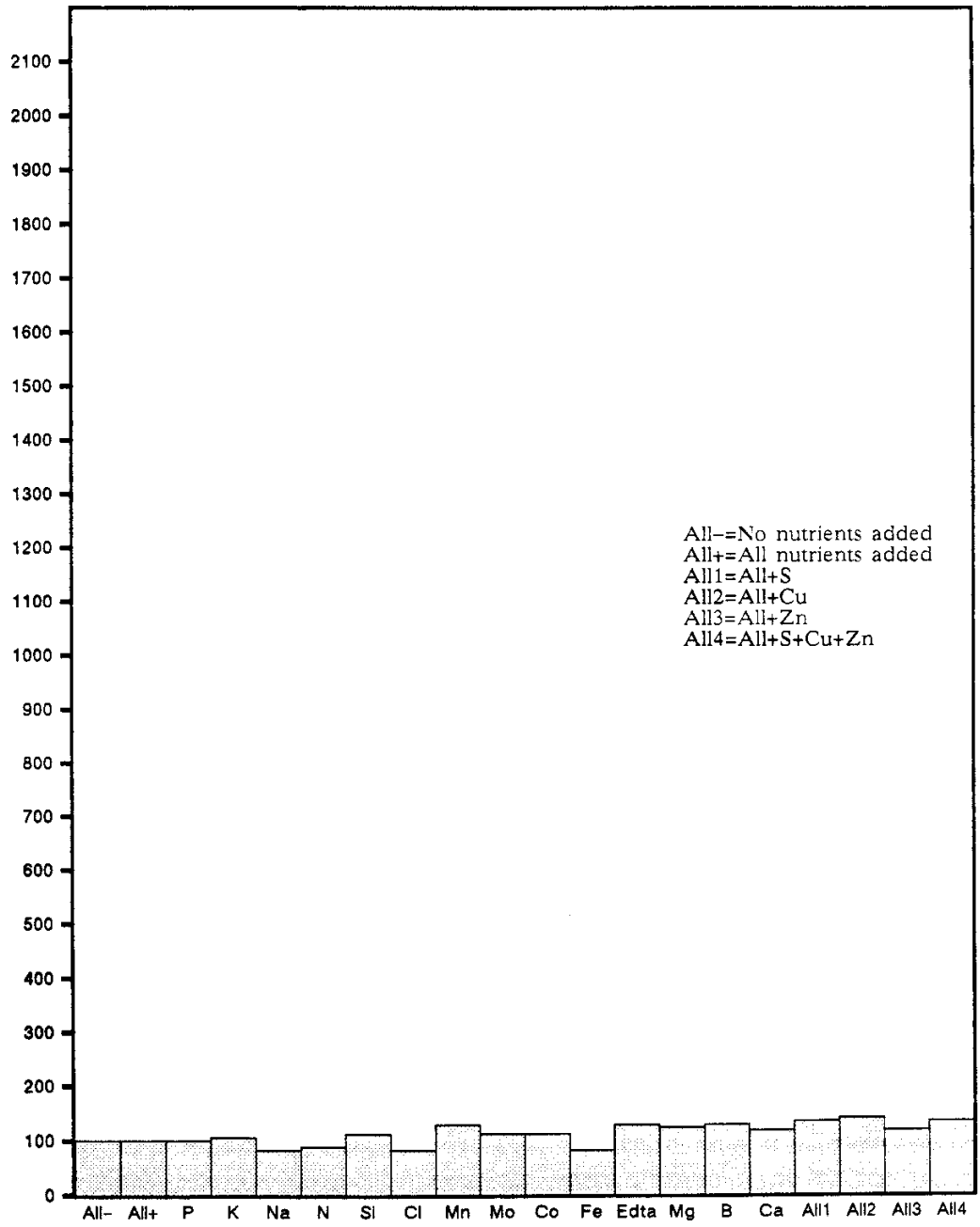
Appendix 4e. Algal growth (as percentage of control with no added nutrients) for various nutrients deleted from bioassay bottles during October 1986.



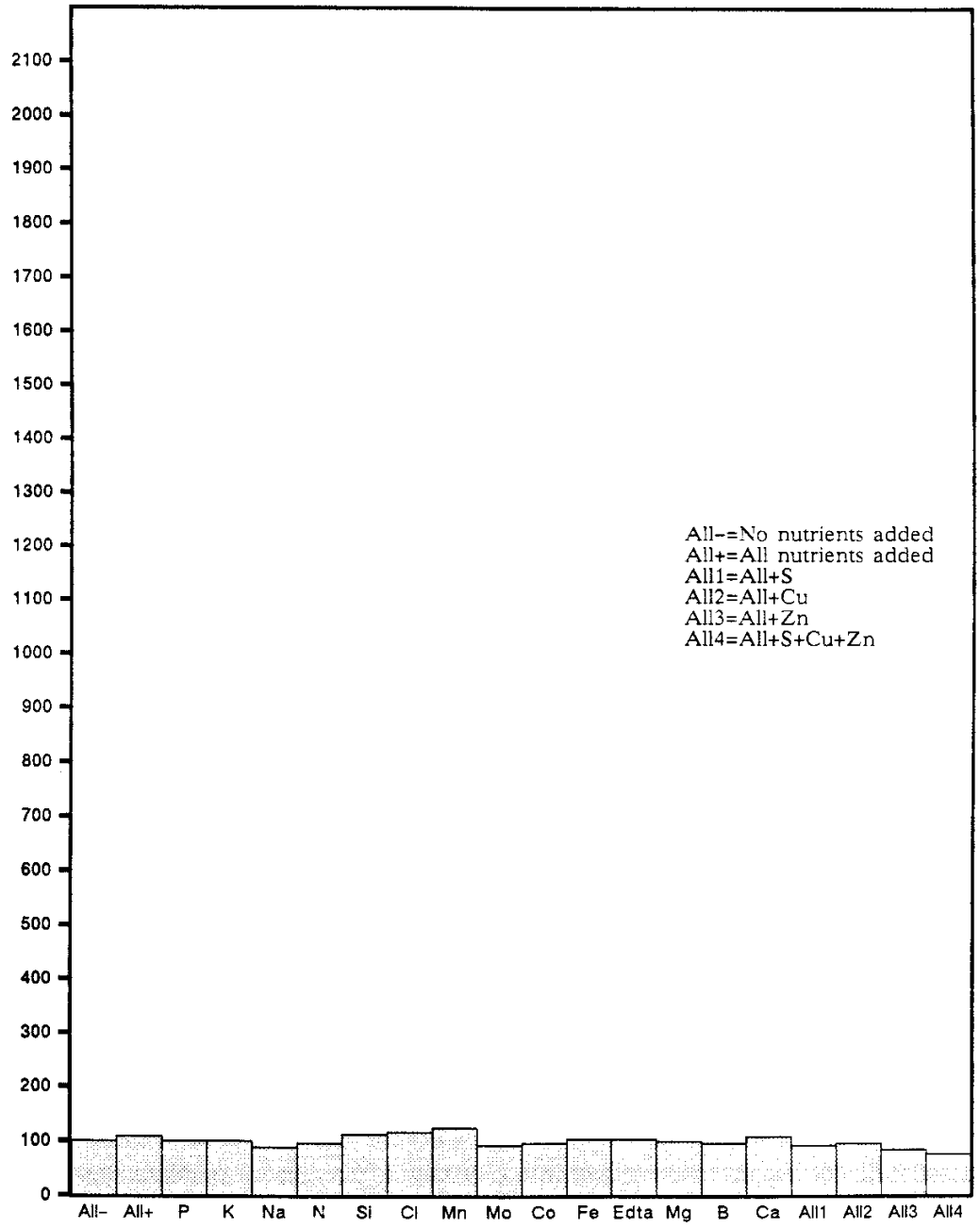
Appendix 4f. Algal growth (as percentage of control with no added nutrients) for various nutrients deleted from bioassay bottles during November 1986.



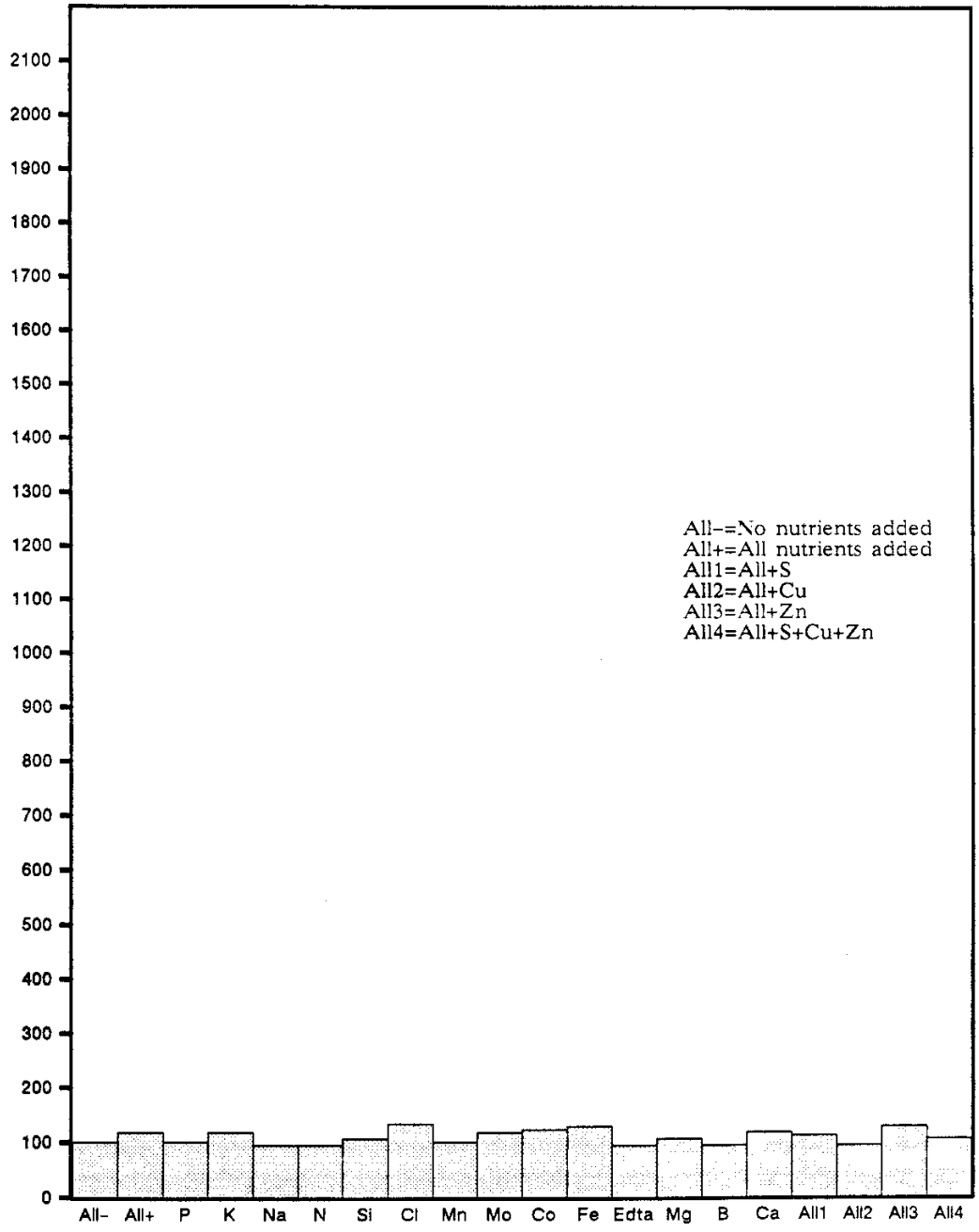
Appendix 4g. Algal growth (as percentage of control with no added nutrients) for various nutrients deleted from bioassay bottles during December 1986.



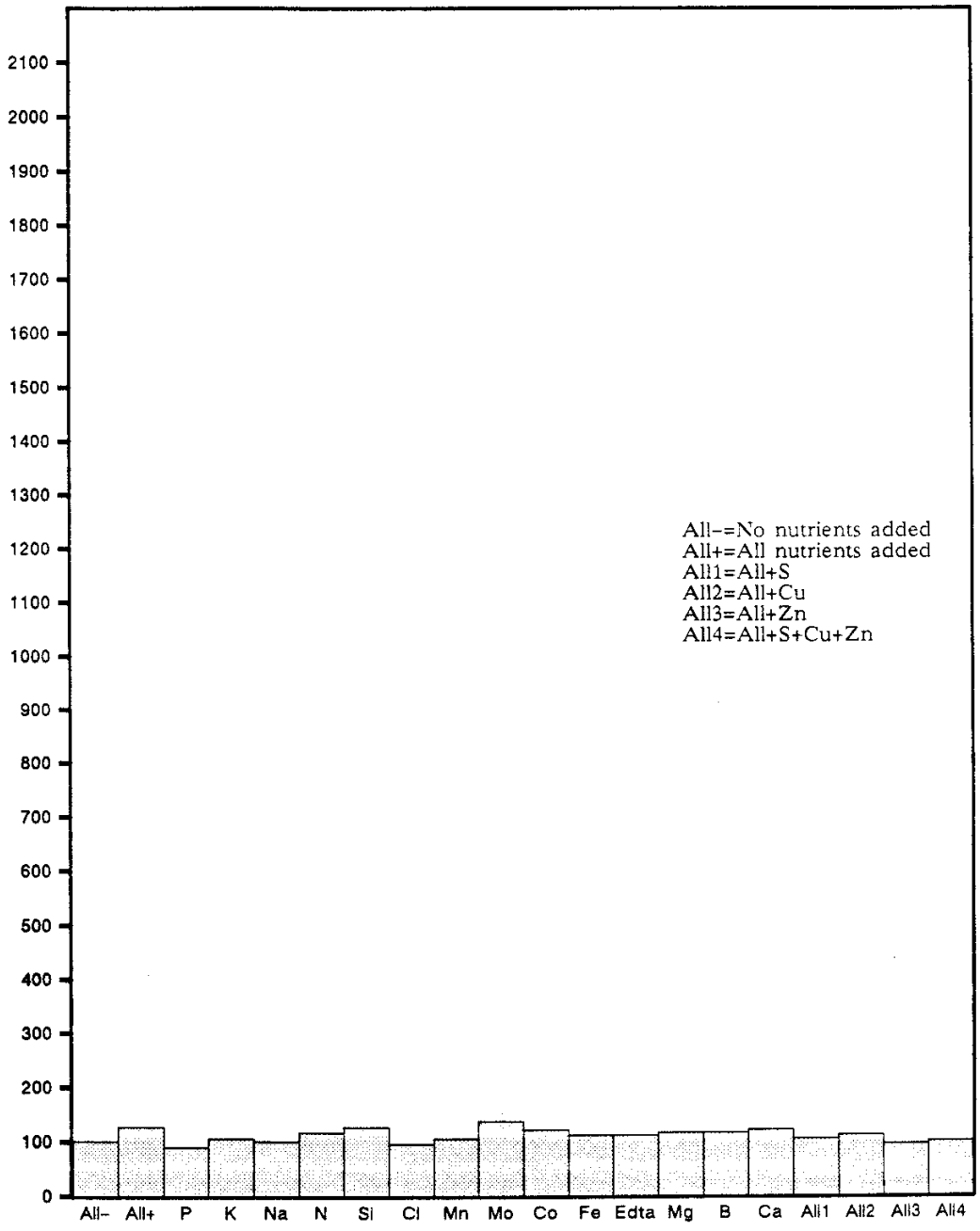
Appendix 4h. Algal growth (as percentage of control with no added nutrients) for various nutrients deleted from bioassay bottles during January 1987.



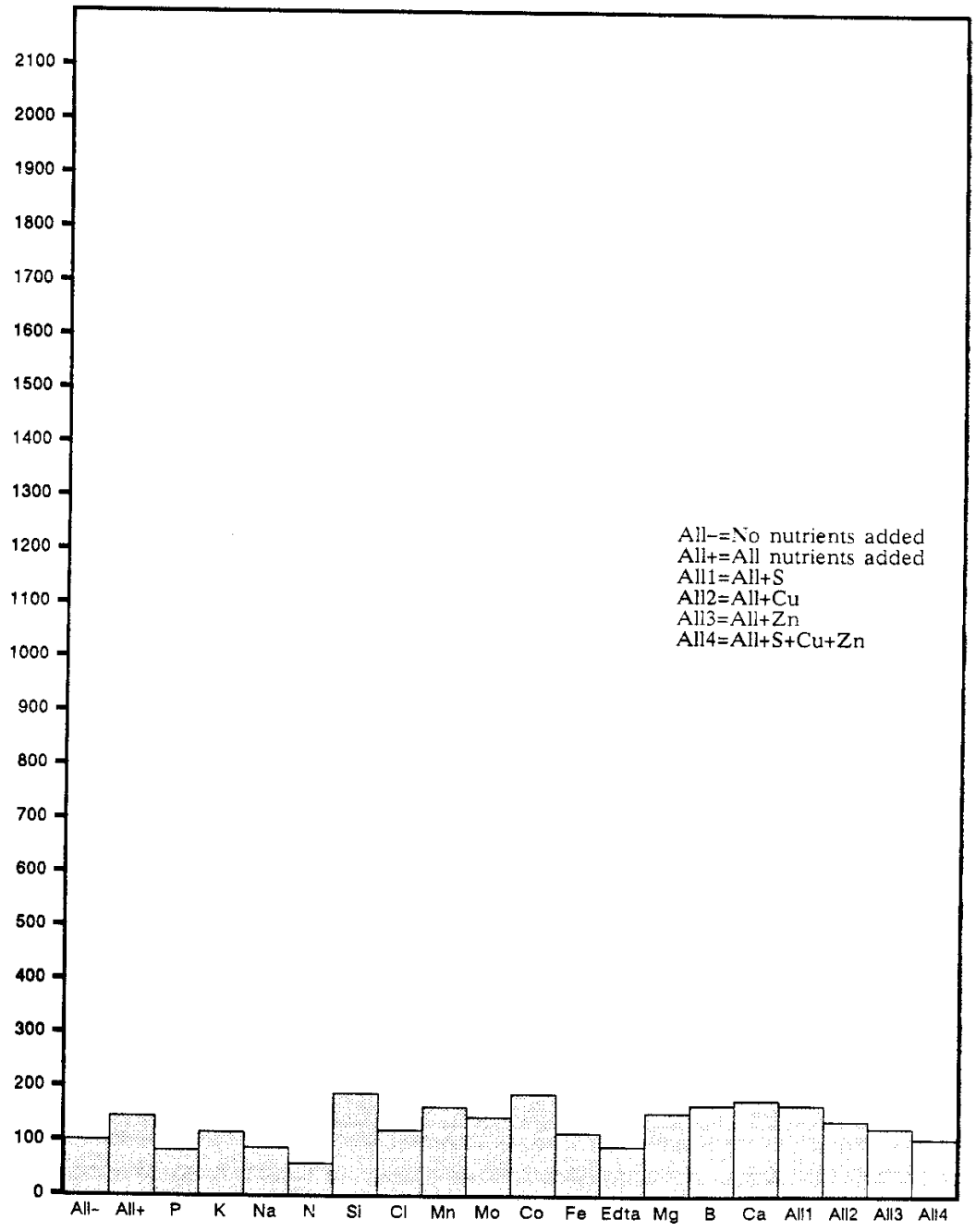
Appendix 4i. Algal growth (as percentage of control with no added nutrients) for various nutrients deleted from bioassay bottles during Febuary 1987.



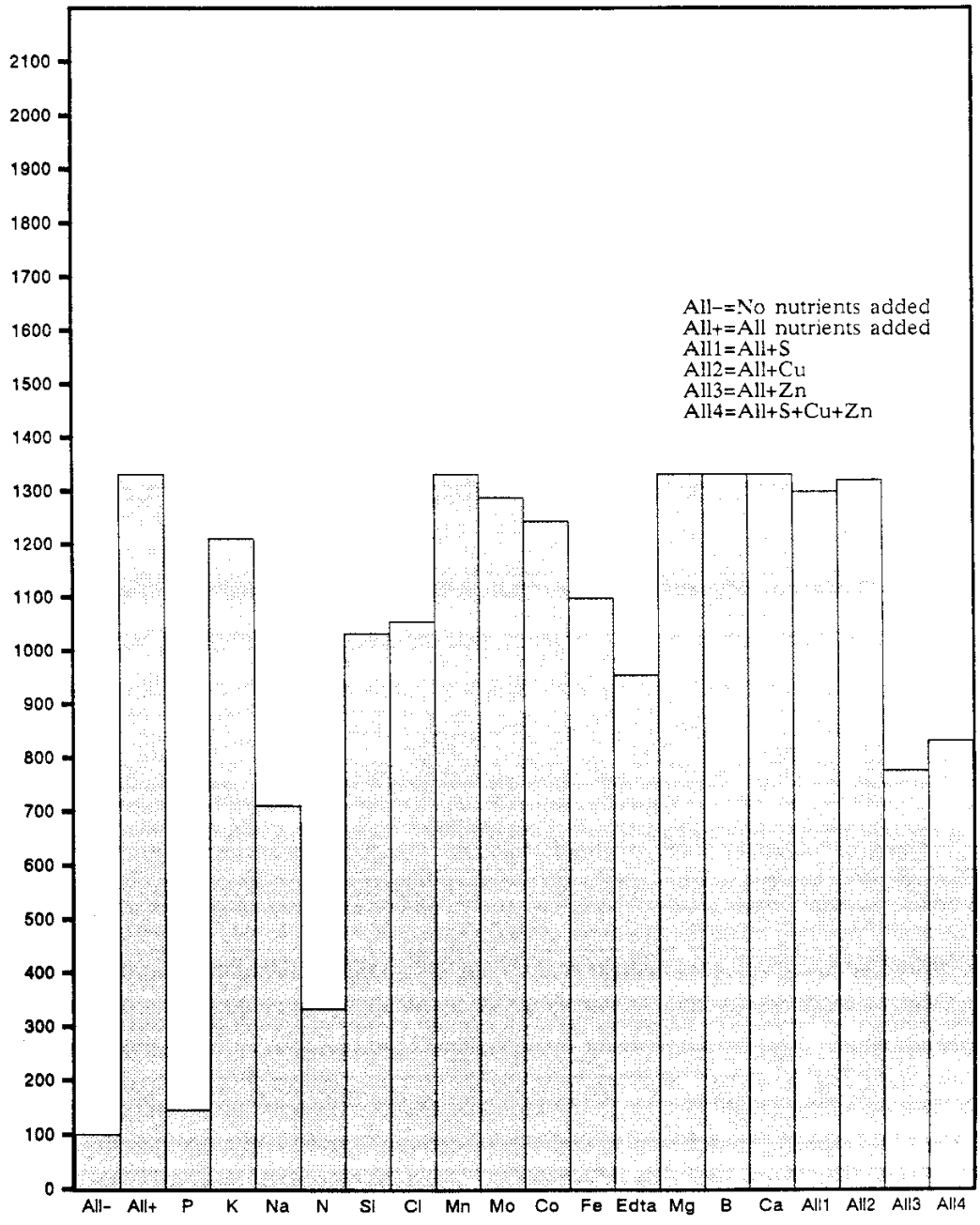
Appendix 4j. Algal growth (as percentage of control with no added nutrients) for various nutrients deleted from bioassay bottles during March 1987.



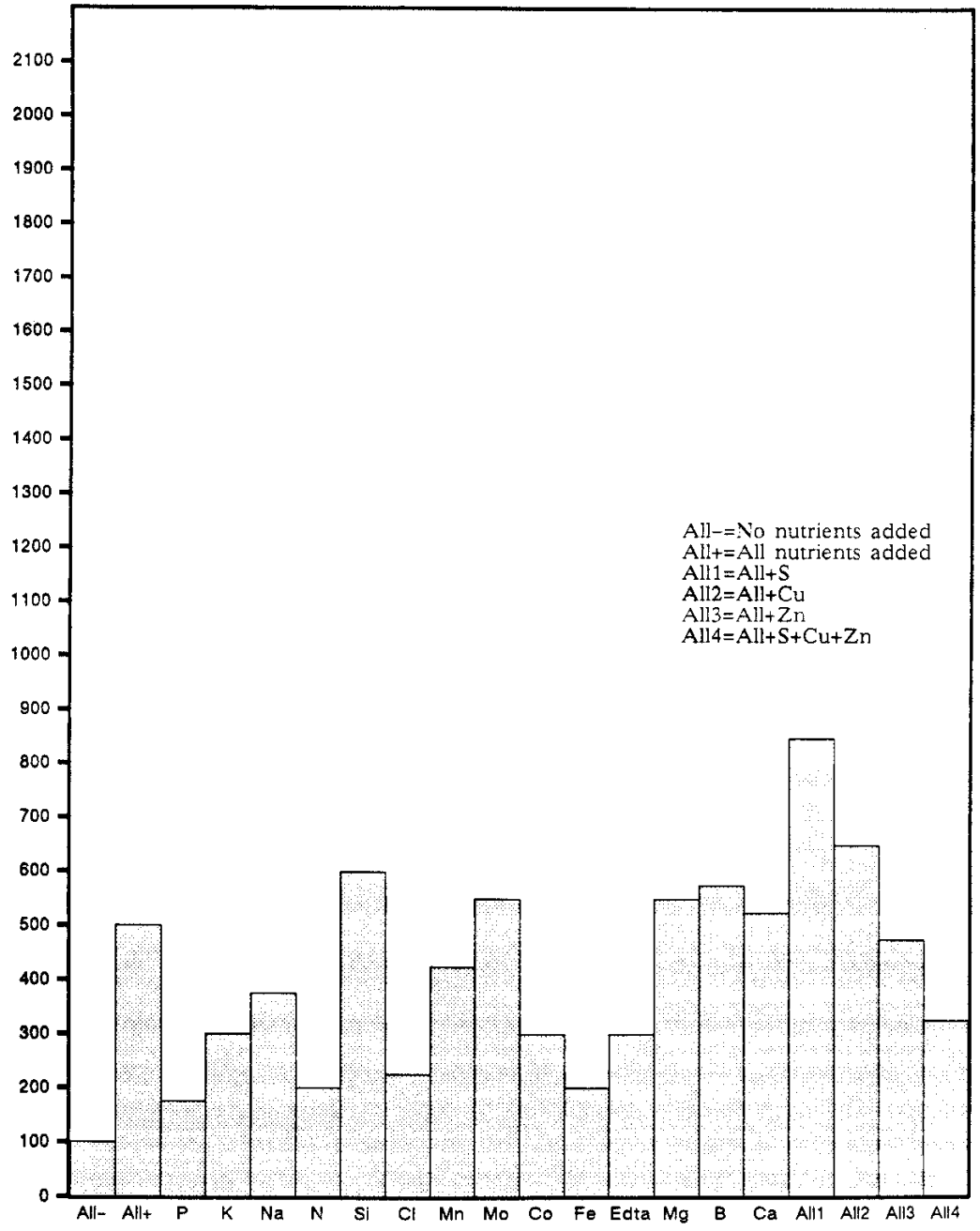
Appendix 4k. Algal growth (as percentage of control with no added nutrients) for various nutrients deleted from bioassay bottles during April 1987.



Appendix 4l. Algal growth (as percentage of control with no added nutrients) for various nutrients deleted from bioassay bottles during May 1987.



Appendix 4m. Algal growth (as percentage of control with no added nutrients) for various nutrients deleted from bioassay bottles during June 1987.



Appendix 5. Phytoplankton Collected from Morris Reservoir Near the Dam - April 24, 1986

	Surf.		3m		6m		9m		12m	
	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3
Myxophyceae										
Anabaena					39	392			20	201
Aphanizomenon										
Gomphosphaeria										
Chlorophyceae										
Ankistrodesmus	644	182	136	38					20	17
Chlamydomonas										
Chodetella										
Closteriopsis										
Elakatothrix										
Golenkinia										
Scenedesmus										
Schroederia										
Selenastrum										
Sphaerocystis										
Staurastrum										
Bacillariophyceae										
Asterionella					20	90				
Cocconeis										
Cyclotella										
Fragilaria										
Gomphonema										
Melosira										
Navicula										
Pinnularia										
Stauroneis										
Synedra										
Chrysophyceae										
Dinobryon										
Crytophyceae										
Cryptomonas										
Unidentified	78	20	58	15	39	10	98	25	58	15
Euglenophyceae										
Trachelomonas										

Appendix 5. Phytoplankton Collected from Morris Reservoir Near the Dam - May 21, 1986

	Surf.		3m		6m		9m		12m	
	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3
Myxophyceae										
Anabaena										
Aphanizomenon	98	277	332	1,876	332	940	78	221	58	328
Gomphosphaeria										
Chlorophyceae										
Ankistrodesmus			78	22	332	94	117	33	117	33
Chlamydomonas										
Chodetella										
Closteriopsis										
Elakatothrix										
Golenkinia										
Scenedesmus										
Schroederia										
Selenastrum										
Sphaerocystis										
Staurastrum										
Bacillariophyceae										
Asterionella										
Cocconeis										
Cyclotella										
Fragilaria										
Gomphonema										
Melosira										
Navicula										
Pinnularia										
Stauroneis										
Synedra										
Chrysophyceae										
Dinobryon	20	1	117	87						
Crytophyceae										
Cryptomonas					20	62				
Unidentified			20	5	39	10				
Euglenophyceae										
Trachelomonas										

Appendix 5. Phytoplankton Collected from Morris Reservoir Near the Dam - June 5, 1986

	Surf.		3m		6m		9m		12m	
	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3
Myxophyceae										
Anabaena										
Aphanizomenon	722	4,079	410	1,738	370	1,569	176	498		
Gomphosphaeria										
Chlorophyceae										
Ankistrodesmus	1,014	287	663	188	39	11			98	28
Chlamydomonas										
Chodetella										
Closteriopsis										
Elakatothrix										
Golenkinia										
Scenedesmus										
Schroederia										
Selenastrum										
Sphaerocystis										
Staurastrum										
Bacillariophyceae										
Asterionella										
Cocconeis										
Cyclotella										
Fragilaria										
Gomphonema										
Melosira										
Navicula										
Pinnularia										
Stauroneis										
Synedra										
Chrysophyceae										
Dinobryon	195	145	292	217						
Crytophyceae										
Cryptomonas										
Unidentified			20	12	98	59				
Euglenophyceae										
Trachelomonas										

Appendix 5. Phytoplankton Collected from Morris Reservoir Near the Dam - June 18, 1986

	Surf.		3m		6m		9m		12m	
	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3
Myxophyceae										
Anabaena										
Aphanizomenon	3,354	18,950	3,920	23,089	760	1,908	39	49	117	25
Gomphosphaeria										
Chlorophyceae										
Ankistrodesmus	488	138	292	147	370	78				
Chlamydomonas	58	35	1,989	505	273	69				
Chodetella										
Closteriopsis										
Elakatothrix										
Golenkinia										
Scenedesmus										
Schroederia										
Selenastrum										
Sphaerocystis										
Staurastrum										
Bacillariophyceae										
Asterionella										
Cocconeis										
Cyclotella										
Fragilaria										
Gomphonema										
Melosira										
Navicula			20	503						
Pinnularia										
Stauroneis										
Synedra										
Chrysophyceae										
Dinobryon	312	232	644	478						
Crytophyceae										
Cryptomonas										
Unidentified										
Euglenophyceae										
Trachelomonas										

Appendix 5. Phytoplankton Collected from Morris Reservoir Near the Dam - July 9, 1986

	Surf.		3m		6m		9m		12m	
	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3
Myxophyceae										
Anabaena										
Aphanizomenon	98	577	176	692	2,398	9,424	98	554	98	184
Gomphosphaeria										
Chlorophyceae										
Ankistrodesmus	98	21	78	17						
Chlamydomonas			39	24	1,404	847				
Chodetella										
Closteriopsis										
Elakatothrix										
Golenkinia										
Scenedesmus										
Schroederia										
Selenastrum										
Sphaerocystis										
Staurastrum										
Bacillariophyceae										
Asterionella										
Cocconeis										
Cyclotella										
Fragilaria										
Gomphonema										
Melosira										
Navicula										
Pinnularia										
Stauroneis										
Synedra										
Chrysophyceae										
Dinobryon					20	15				
Crytophyceae										
Cryptomonas										
Unidentified										
Euglenophyceae										
Trachelomonas										

Appendix 5. Phytoplankton Collected from Morris Reservoir Near the Dam - July 24, 1986

	Surf.		3m		5m		6m		9m		12m	
	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3
Myxophyceae												
Anabaena												
Aphanizomenon	176	222	78	118	1,540	1,161	2,398	4,508			20	25
Gomphosphaeria												
Chlorophyceae												
Ankistrodesmus												
Chlamydomonas					98	59						
Chodetella												
Closteriopsis												
Elakatothrix												
Golenkinia												
Scenedesmus												
Schroederia	254	96	351	132	117	44	20	8	39	11	39	11
Selenastrum												
Sphaerocystis												
Staurastrum												
Bacillariophyceae												
Asterionella												
Cocconeis												
Cyclotella												
Fragilaria												
Gomphonema												
Melosira												
Navicula												
Pinnularia												
Stauroneis												
Synedra												
Chrysophyceae												
Dinobryon	39	29	58	43	117	87						
Crytophyceae												
Cryptomonas					98	59						
Unidentified												
Euglenophyceae												
Trachelomonas												

Appendix 5. Phytoplankton Collected from Morris Reservoir Near the Dam - August 7, 1986

	Surf.		3m		6m		9m		11m	
	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3
Myxophyceae										
Anabaena										
Aphanizomenon	117	147	604	1,136	2,769	5,206	20	38	20	25
Gomphosphaeria										
Chlorophyceae										
Ankistrodesmus										
Chlamydomonas	58	35								
Chodetella										
Closteriopsis										
Elakatothrix										
Golenkinia										
Scenedesmus										
Schroederia	488	184	195	74	117	44	58	22	58	22
Selenastrum										
Sphaerocystis										
Staurastrum										
Bacillariophyceae										
Asterionella										
Cocconeis										
Cyclotella										
Fragilaria										
Gomphonema										
Melosira										
Navicula										
Pinnularia										
Stauroneis										
Synedra										
Chrysophyceae										
Dinobryon			58	43						
Crytophyceae										
Cryptomonas					20	62				
Unidentified										
Euglenophyceae										
Trachelomonas										

Appendix 5. Phytoplankton Collected from Morris Reservoir Near the Dam - August 21, 1986

	Surf.		3m		6m		9m		10.5m	
	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3
Myxophyceae										
Anabaena										
Aphanizomenon	448	1,761	351	1,488	214	1,209				
Gomphosphaeria										
Chlorophyceae										
Ankistrodesmus										
Chlamydomonas			448	270	78	47	20	12		
Chodetella										
Closteriopsis										
Elakatothrix										
Golenkinia										
Scenedesmus									20	22
Schroederia	234	88	351	132	1,228	260			98	37
Selenastrum										
Sphaerocystis										
Staurastrum										
Bacillariophyceae										
Asterionella										
Cocconeis										
Cyclotella									20	69
Fragilaria										
Gomphonema										
Melosira										
Navicula										
Pinnularia										
Stauroneis										
Synedra					78	1,838	20	471		
Chrysophyceae										
Dinobryon										
Crytophyceae										
Cryptomonas	20	62	39	120						
Unidentified										
Euglenophyceae										
Trachelomonas										

Appendix 5. Phytoplankton Collected from Morris Reservoir Near the Dam - September 11, 1986

	Surf.		3m		6m		9.5m	
	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3
Myxophyceae								
Anabaena								
Aphanizomenon	1,365	11,575	1,228	1,041	1,618	4,061	390	2,204
Gomphosphaeria								
Chlorophyceae								
Ankistrodesmus								
Chlamydomonas								
Chodetella								
Closteriopsis	682	578	20	17				
Elakatothrix								
Golenkinia								
Scenedesmus								
Schroederia	1,209	256	98	21	3,100	1,169		
Selenastrum								
Sphaerocystis								
Staurastrum								
Bacillariophyceae								
Asterionella								
Cocconeis								
Cyclotella								
Cymbella							20	68
Fragilaria								
Gomphonema								
Melosira								
Navicula								
Pinnularia								
Stauroneis								
Synedra								
Chrysophyceae								
Dinobryon								
Crytophyceae								
Cryptomonas								
Unidentified								
Euglenophyceae								
Trachelomonas								

Appendix 5. Phytoplankton Collected from Morris Reservoir Near the Dam - September 25, 1986

	Surf.		3m		6m		8.5m		9m	
	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3
Myxophyceae										
Anabaena										
Aphanizomenon	390	1,151	273	1,542	98	554	176	994	312	1,763
Gomphosphaeria										
Chlorophyceae										
Ankistrodesmus										
Chlamydomonas	4,953	2,987	98	59			20	12		
Chodetella										
Closteriopsis										
Elakatothrix										
Golenkinia										
Scenedesmus			39	62			20	32		
Schroederia	98	246	58	12	39	15	39	8	78	29
Selenastrum										
Sphaerocystis										
Staurastrum										
Bacillariophyceae										
Asterionella										
Cocconeis										
Cyclotella										
Fragilaria										
Gomphonema										
Melosira			20	302						
Navicula										
Pinnularia										
Stauroneis										
Synedra	20	157								
Chrysophyceae										
Dinobryon										
Crytophyceae										
Cryptomonas	58	197	58	350						
Unidentified										
Euglenophyceae										
Trachelomonas										

Appendix 5. Phytoplankton Collected from Morris Reservoir Near the Dam - October 10, 1986

	Surf.		3m		6m		9m	
	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3
Myxophyceae								
Anabaena								
Aphanizomenon								
Gomphosphaeria								
Chlorophyceae								
Ankistrodesmus								
Chlamydomonas								
Chodetella								
Closteriopsis								
Elakatothrix								
Golenkinia							6,708	48,559
Scenedesmus	448	1,380	1,150	2,346			351	555
Schroederia	39	15	195	74	39	8		
Selenastrum								
Sphaerocystis							1,404	16,138
Staurastrum								
Bacillariophyceae								
Asterionella							896	2,702
Cocconeis								
Cyclotella								
Fragilaria							40	206
Gomphonema								
Melosira			312	4,165			25,350	179,225
Navicula								
Pinnularia								
Stauroneis							40	1,368
Synedra			117	1,838	20	471	4,250	100,130
Chrysophyceae								
Dinobryon								
Crytophyceae								
Cryptomonas			507	918				
Unidentified								
Euglenophyceae								
Trachelomonas								

Appendix 5. Phytoplankton Collected from Morris Reservoir Near the Dam - October 24, 1986

	Surf.		3m		6m		9m	
	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3
Myxophyceae								
Anabaena								
Aphanizomenon	20	85			20	63		
Gomphosphaeria								
Chlorophyceae								
Ankistrodesmus								
Chlamydomonas	273	165	117	71	39	24	20	133
Chodetella								
Closteriopsis								
Elakatothrix								
Golenkinia								
Scenedesmus	5,012	5,513	3,530	5,577	2,184	2,402	5,012	5,513
Schroederia	292	110	448	95	195	74	448	168
Selenastrum								
Sphaerocystis								
Staurastrum								
Bacillariophyceae								
Asterionella								
Cocconeis								
Cyclotella								
Fragilaria								
Gomphonema								
Melosira					20	470		
Navicula								
Pinnularia								
Stauroneis								
Synedra								
Chrysophyceae								
Dinobryon								
Crytophyceae								
Cryptomonas								
Unidentified								
Euglenophyceae								
Trachelomonas								

Appendix 5. Phytoplankton Collected from Morris Reservoir Near the Dam - November 6, 1986

	Surf.		3m		6m		8.5m	
	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3
Myxophyceae								
Anabaena					20	151		
Aphanizomenon			98	739			20	201
Gomphosphaeria								
Chlorophyceae								
Ankistrodesmus								
Chlamydomonas					20	12		
Chodetella								
Closteriopsis								
Elakatothrix								
Golenkinia								
Scenedesmus	9,068	9,975	7,976	8,774	5,694	6,263	7,956	8,752
Schroederia	468	176	214	81	195	74	410	155
Selenastrum								
Sphaerocystis								
Staurastrum								
Bacillariophyceae								
Asterionella								
Cocconeis								
Cyclotella								
Fragilaria								
Gomphonema								
Melosira								
Navicula								
Pinnularia			20	157				
Stauroneis								
Synedra								
Chrysophyceae								
Dinobryon								
Crytophyceae								
Cryptomonas								
Unidentified								
Euglenophyceae								
Trachelomonas								

Appendix 5. Phytoplankton Collected from Morris Reservoir Near the Dam - November 21, 1986

	Surf.		3m		6m		8m	
	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3
Myxophyceae								
Anabaena	78	236	39	176				
Aphanizomenon								
Gomphosphaeria								
Chlorophyceae								
Ankistrodesmus								
Chlamydomonas	98	59	58	35				
Chodetella								
Closteriopsis								
Elakatothrix								
Golenkinia								
Scenedesmus	16,497	15,540	22,113	20,830	12,968	12,216	13,474	12,693
Schroederia	20	10	58	36			98	62
Selenastrum								
Sphaerocystis								
Staurastrum								
Bacillariophyceae								
Asterionella								
Cocconeis								
Cyclotella								
Fragilaria								
Gomphonema								
Melosira								
Navicula								
Pinnularia								
Stauroneis								
Synedra								
Chrysophyceae								
Dinobryon	20	15						
Crytophyceae								
Cryptomonas	98	302	234	721	195	3,681	58	179
Unidentified								
Euglenophyceae								
Trachelomonas								

Appendix 5. Phytoplankton Collected from Morris Reservoir Near the Dam - December 11, 1986

	Surf.		3m		6m		7.5m	
	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3
Myxophyceae								
Anabaena								
Aphanizomenon								
Gomphosphaeria								
Chlorophyceae								
Ankistrodesmus								
Chlamydomonas	98	59	58	35	39	24		
Chodetella					20	29		
Closteriopsis	20	10						
Elakatothrix								
Golenkinia	20	18						
Scenedesmus	7,664	12,032	5,226	5,749	4,875	5,363	6,240	9,797
Schroederia			20	4	39	20		
Selenastrum								
Sphaerocystis								
Staurastrum								
Bacillariophyceae								
Asterionella					20	80		
Cocconeis								
Cyclotella								
Fragilaria								
Gomphonema					20	817		
Melosira	20	314						
Navicula								
Pinnularia							39	429
Stauroneis								
Synedra								
Chrysophyceae								
Dinobryon							58	43
Crytophyceae								
Cryptomonas	58	233	117	324	20	41	78	194
Unidentified								
Euglenophyceae								
Trachelomonas								

Appendix 5. Phytoplankton Collected from Morris Reservoir Near the Dam - December 23, 1986

	Surf.		3m		6m		8m	
	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3
Myxophyceae								
Anabaena								
Aphanizomenon								
Gomphosphaeria								
Chlorophyceae								
Ankistrodesmus								
Chlamydomonas	234	141	117	71	20	12		
Chodetella	20	10						
Closteriopsis								
Elakatothrix								
Golenkinia								
Scenedesmus	3,939	7,130	3,003	4,715	4,388	4,827	5,148	9,318
Schroederia	39	34			58	30	39	34
Selenastrum								
Sphaerocystis								
Staurastrum								
Bacillariophyceae								
Asterionella	20	53	1,326	4,669				
Cocconeis								
Cyclotella								
Fragilaria								
Gomphonema								
Melosira			254	3,830				
Navicula								
Pinnularia								
Stauroneis								
Synedra	20	27	20	251				
Chrysophyceae								
Dinobryon	20	15	546	405	39	29		
Crytophyceae								
Cryptomonas	702	1,945	1,853	5,707	98	302	39	108
Unidentified								
Euglenophyceae								
Trachelomonas								

Appendix 5. Phytoplankton Collected from Morris Reservoir Near the Dam - January 9, 1987

	Surf.		3m		6m		9m		11m	
	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3
Myxophyceae										
Anabaena										
Aphanizomenon										
Gomphosphaeria										
Chlorophyceae										
Ankistrodesmus										
Chlamydomonas			58	35	78	4,730				
Chodetella										
Closteriopsis										
Elakatothrix										
Golenkinia										
Scenedesmus	370	585	741	2,179	916	1,585	936	1,694	702	885
Schroederia					20	13				
Selenastrum										
Sphaerocystis										
Staurastrum										
Bacillariophyceae										
Asterionella			39	157						
Cocconeis										
Cyclotella										
Fragilaria										
Gomphonema										
Melosira										
Navicula										
Pinnularia										
Stauroneis										
Synedra					20	113				
Chrysophyceae										
Dinobryon					20	15				
Crytophyceae										
Cryptomonas									20	45
Unidentified										
Euglenophyceae										
Trachelomonas										

Appendix 5. Phytoplankton Collected from Morris Reservoir Near the Dam - January 22, 1987

	Surf.		3m		6m		9m		11m	
	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3
Myxophyceae										
Anabaena										
Aphanizomenon										
Gomphosphaeria										
Chlorophyceae										
Ankistrodesmus										
Chlamydomonas			39	24	39	24				
Chodetella										
Closteriopsis										
Elakatothrix										
Golenkinia										
Scenedesmus	254	574	546	1,234	488	883	292	321	760	1,376
Schroederia										
Selenastrum										
Sphaerocystis										
Staurastrum										
Bacillariophyceae										
Asterionella					39	157	39	157		
Cocconeis										
Cyclotella										
Fragilaria										
Gomphonema										
Melosira										
Navicula										
Pinnularia										
Stauroneis										
Synedra										
Chrysophyceae										
Dinobryon										
Crytophyceae										
Cryptomonas	98	473	78	439						
Unidentified										
Euglenophyceae										
Trachelomonas										

Appendix 5. Phytoplankton Collected from Morris Reservoir Near the Dam - February 5, 1987

	Surf.		3m		6m		9m		11.5m	
	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3
Myxophyceae										
Anabaena										
Aphanizomenon										
Gomphosphaeria										
Chlorophyceae										
Ankistrodesmus										
Chlamydomonas	39	24	156	94			58	35		
Chodetella										
Closteriopsis										
Elakatothrix										
Golenkinia										
Scenedesmus	20	25	176	319	448	811	838	1,517	468	1,058
Schroederia										
Selenastrum										
Sphaerocystis										
Staurastrum										
Bacillariophyceae										
Asterionella			20	80					20	80
Cocconeis			20	62						
Cyclotella										
Fragilaria										
Gomphonema										
Melosira										
Navicula										
Pinnularia										
Stauroneis										
Synedra										
Chrysophyceae										
Dinobryon					20	15				
Crytophyceae										
Cryptomonas	370	2,083	507	2,854			58	327	20	97
Unidentified										
Euglenophyceae										
Trachelomonas										

Appendix 5. Phytoplankton Collected from Morris Reservoir Near the Dam - February 18, 1987

	Surf.		3m		6m		9m		12m	
	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3
Myxophyceae										
Anabaena										
Aphanizomenon										
Gomphosphaeria										
Chlorophyceae										
Ankistrodesmus										
Chlamydomonas			117	71	20	12	78	47		
Chodetella										
Closteriopsis										
Elakatothrix										
Golenkinia										
Scenedesmus			156	197	78	176	78	122	39	61
Schroederia										
Selenastrum										
Sphaerocystis										
Staurastrum										
Bacillariophyceae										
Asterionella										
Cocconeis										
Cyclotella										
Fragilaria					20	118				
Gomphonema										
Melosira										
Navicula										
Pinnularia										
Stauroneis										
Synedra										
Chrysophyceae										
Dinobryon										
Crytophyceae										
Cryptomonas	78	377								
Unidentified										
Euglenophyceae										
Trachelomonas										

Appendix 5. Phytoplankton Collected from Morris Reservoir Near the Dam - March 4, 1987

	Surf.		3m		6m		9m		12m	
	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3
Myxophyceae										
Anabaena										
Aphanizomenon										
Gomphosphaeria										
Chlorophyceae										
Ankistrodesmus										
Chlamydomonas	58	35							39	24
Chodetella										
Closteriopsis										
Elakatothrix										
Golenkinia										
Scenedesmus							58	79	78	86
Schroederia										
Selenastrum										
Sphaerocystis										
Staurastrum										
Bacillariophyceae										
Asterionella										
Cocconeis										
Cyclotella										
Fragilaria										
Gomphonema										
Melosira										
Navicula										
Pinnularia										
Stauroneis										
Synedra									20	141
Chrysophyceae										
Dinobryon										
Crytophyceae										
Cryptomonas	58	280	98	591	214	1,290				
Unidentified										
Euglenophyceae										
Trachelomonas										

Appendix 5. Phytoplankton Collected from Morris Reservoir Near the Dam - March 17, 1987

	Surf.		3m		6m		9m		13m	
	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3
Myxophyceae										
Anabaena										
Aphanizomenon										
Gomphosphaeria										
Chlorophyceae										
Ankistrodesmus										
Chlamydomonas	20	12					20	12	20	12
Chodetella										
Closteriopsis										
Elakatothrix										
Golenkinia									20	31
Scenedesmus										
Schroederia										
Selenastrum										
Sphaerocystis										
Staurastrum										
Bacillariophyceae										
Asterionella									20	80
Cocconeis										
Cyclotella										
Fragilaria										
Gomphonema										
Melosira										
Navicula										
Pinnularia										
Stauroneis										
Synedra	20	141								
Chrysophyceae										
Dinobryon										
Crytophyceae										
Cryptomonas										
Unidentified										
Euglenophyceae										
Trachelomonas										

Appendix 5. Phytoplankton Collected from Morris Reservoir Near the Dam - April 3, 1987

	Surf.		3m		6m		9m		12m		13m	
	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3
Myxophyceae												
Anabaena												
Aphanizomenon												
Gomphosphaeria												
Chlorophyceae												
Ankistrodesmus												
Chlamydomonas	39	24	20	12			20	12	58	35	136	82
Chodetella												
Closteriopsis												
Elakatothrix												
Golenkinia												
Scenedesmus									39	43		
Schroederia												
Selenastrum												
Sphaerocystis												
Staurastrum											20	80
Bacillariophyceae												
Asterionella												
Cocconeis												
Cyclotella					20	2.413						
Fragilaria												
Gomphonema												
Melosira											20	628
Navicula												
Pinnularia												
Stauroneis												
Synedra	20	57										
Chrysophyceae												
Dinobryon	20	15										
Crytophyceae												
Cryptomonas	176	488	78	439	78	377						
Unidentified												
Euglenophyceae												
Trachelomonas												

Appendix 5. Phytoplankton Collected from Morris Reservoir Near the Dam - April 13, 1987

	Surf.		3m		6m		9m		11m		12.5m	
	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3
Myxophyceae												
Anabaena	39	588										
Aphanizomenon												
Gomphosphaeria												
Chlorophyceae												
Ankistrodesmus												
Chlamydomonas			78	47	20	12	58	35				
Chodetella												
Closteriopsis												
Elakatothrix												
Golenkinia												
Scenedesmus												
Schroederia												
Selenastrum												
Sphaerocystis												
Staurastrum												
Bacillariophyceae												
Asterionella					20	80			20	80		
Cocconeis												
Cyclotella												
Fragilaria												
Gomphonema												
Melosira											20	628
Navicula												
Pinnularia												
Stauroneis												
Synedra												
Chrysophyceae												
Dinobryon												
Crytophyceae												
Cryptomonas			20	105								
Unidentified												
Euglenophyceae												
Trachelomonas												

Appendix 5. Phytoplankton Collected from Morris Reservoir Near the Dam - May 7, 1987

	Surf.		3m		6m		9m		12m	
	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3
Myxophyceae										
Anabaena	58	164	254	1,915	20	302				
Aphanizomenon										
Gomphosphaeria			20	102						
Chlorophyceae										
Ankistrodesmus										
Chlamydomonas	273	2,305	1,638	988	1,034	624	468	282	254	153
Chodetella										
Closteriopsis										
Elakatothrix			20	30						
Golenkinia										
Scenedesmus					58	91				
Schroederia										
Selenastrum										
Sphaerocystis										
Staurastrum										
Bacillariophyceae										
Asterionella					20	80				
Cocconeis										
Cyclotella	20	1,232								
Fragilaria										
Gomphonema	39	858								
Melosira										
Navicula										
Pinnularia										
Stauroneis										
Synedra	20	251	39	220						
Chrysophyceae										
Dinobryon	4,173	3,096	18,057	13,398	58	43			20	15
Crytophyceae										
Cryptomonas										
Unidentified										
Euglenophyceae										
Trachelomonas										

Appendix 5. Phytoplankton Collected from Morris Reservoir Near the Dam - June 5, 1987

	Surf.		3m		5m		6m		9m		12m	
	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3
Myxophyceae												
Anabaena					20	201	20	80			20	60
Aphanizomenon												
Gomphosphaeria												
Chlorophyceae												
Ankistrodesmus												
Chlamydomonas	370	223	1,209	729	410	247	448	270	58	35	39	24
Chodetella												
Closteriopsis												
Elakatothrix	78	53	58	70								
Golenkinia												
Scenedesmus							39	115				
Schroederia												
Selenastrum												
Sphaerocystis												
Staurastrum												
Bacillariophyceae												
Asterionella			20	80								
Cocconeis					20	49						
Cyclotella												
Fragilaria												
Gomphonema												
Melosira												
Navicula												
Pinnularia												
Stauroneis												
Synedra												
Chrysophyceae												
Dinobryon									39	29		
Crytophyceae												
Cryptomonas												
Unidentified												
Euglenophyceae												
Trachelomonas							2,048	2,943				

Appendix 5. Phytoplankton Collected from Morris Reservoir Near the Dam - June 25, 1987

	Surf.		3m		6m		9m		11m	
	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3	Number Per ml.	Volume 1000 u^3
Myxophyceae										
Anabaena										
Aphanizomenon										
Gomphosphaeria										
Chlorophyceae										
Ankistrodesmus										
Chlamydomonas	488	294	858	517	58	35	156	94	20	12
Chodetella										
Closteriopsis										
Elakatothrix										
Golenkinia										
Scenedesmus							20	27	20	27
Schroederia										
Selenastrum										
Sphaerocystis										
Staurastrum									20	80
Bacillariophyceae										
Asterionella										
Cocconeis									20	36
Cyclotella										
Fragilaria										
Gomphonema										
Melosira										
Navicula										
Pinnularia										
Stauroneis										
Synedra										
Chrysophyceae										
Dinobryon										
Crytophyceae										
Cryptomonas	39	235	117	706	98	591				
Unidentified										
Euglenophyceae										
Trachelomonas										

Appendix 6. LIMNO system proposed for hypolimnetic aeration of Morris Reservoir.

Aqua Technique Inc

Mr. Gerald Boles
California Dept. of Water Resources
2440 Main St.
P.O. Box 607
Red Bluff, CA 96080

November 24, 1987

Dear Mr. Boles,

Thank you for the interest shown in the possible application of our LIMNO hypolimnetic aeration system in the Morris Reservoir. We beleive that LIMNO offers a very cost effective approch for dealing with water quality problems of the nature that are being experienced in that body of water.

After more detailed review of the more recent information and data provided, it is felt that a larger system, than discussed verbally, supplying 185 kg of oxygen per day will be required to achieve positive results. Our project proposal is enclosed for your review along with the following information:

1. LIMNO - Project Proposal
2. LIMNO Performance/Cost Estimates
3. LIMNO Leaflet w/Sizing Information
4. Atlas Copco L Series Compressor Leaflet
5. Map of Proposed LIMNO and Compressor Locations
6. Conditions of Sale

Because the air compressor is the heart of any aeration system, we would highly recommend consideration of a back-up unit. The cost would be $2795.00 addition not including freight and installation.

You will note that we have formed a new company as a result of Atlas Copco selling the Lake/Reservoir Management product line to another organization. We offer the same services as before and maintain a relationship with Atlas Copco in the supply of the compressors.

Please contact me if any questions arise.

Richard Geney

cc: R. Roger
J. Natalino
B. Verner

70 Demarest Drive, Wayne, New Jersey 07470
Telephone (201) 696-0554 Telex 219227

Aqua Technique Inc

LIMNO - Project Proposal

CUSTOMER: California Dept. of Water Resources DATE: 11/24/87
2440 Main St.
P.O.Box 607
Red Bluff, CA 96080
CONTACT: Mr. Gerald Boles

TELEPHONE: (916) 527-6530

PROJECT: Morris Reservoir Hypolimnetic Aeration

*Oxygen to be supplied 185 kg/Day

Aqua Technique Supplied LIMNO System Includes:

Project Engineering
(/) LIMNO Units Model 15 26 100
33 Ft. High 9Ft. O.D.
(/) Aircooled, Reciprocating Air Compressor
w/Aftercooler, Seperator and Magnetic Starter
Model 7LE9-80H 41 CFM at 40 psig 7.5 HP Motor
Accessory Items - Air Supply Lines, Anchors,
Regulating System, Oil Seperator Filter
Installation Supervision for LIMNO Units and
Expenses

PRICE: $54,460.00

Customer (Contractor) Supplied Items and Services:

Installation Labor and Supervision
Diver Team
Boats
Crane
Plumbing and Electrical Services
Freight

ESTIMATED PRICE: $10,000.00

TOTAL ESTIMATED PRICE: $64,460.00
(Not including State or Local Taxes where applicable)

NOTE: This price does not include an enclosure for the compressor, bringing electrical power to the site, trenching of air lines or other items not specifically stated.

Price Valid Until: 3/31/88
TERMS: 10% With Order, 80% on Shipment of Material, Net 30 days
Balance on Project Completion Net 30 days.

Material F.O.B Factory: (Estimated Cost Included in Proposal)
Delivery: 8-10 Weeks

* The oxygen supplied includes that which is consumed internally in the unit by the chemical oxygen demand (C.O.D.)

Richard S. Geney
General Manager

70 Demarest Drive Wayne, New Jersey 07470
Telephone (201) 695-0554 Telex 219227

Morris Reservoir

LIMNO Performance/Cost Estimates

kg of O_2 per day	Power (kW) Consumption	kg O_2/ kW hr.	Oper. Cost/ kg O_2/Day (.07/kW hr.)	Oper. Cost/ Day (.07/kW hr.)	Total Project Cost	Installe Cost kg O_2/I
185	5.25	1.46	$ .05	$ 8.82	$ 64,460.	$ 348

⊗ Proposed LIMNO Site

⊠ Proposed Compressor Site

Atlas Copco Aquatec

A Division of Atlas Copco North America

CONDITIONS OF SALE

NOTE: ALL REFERENCES TO ATLAS COPCO AQUATEC SHOULD BE CHANGED TO READ AQUA TECHNIQUE INC.

1. GENERAL. Unless otherwise expressly agreed in writing by a duly authorized representative of Atlas Copco Aquatec, ("Atlas Copco") these terms and conditions supersede all other communications and agreements and notwithstanding any conflicting or different terms and conditions in any order or acceptance of Purchaser, all sales and shipments shall exclusively be governed by these terms and conditions. When used herein "affiliates" shall mean Atlas Copco AB and its wholly-owned subsidiaries. Section headings are for purposes of convenience only. "Products" as used herein shall include products, parts and accessories furnished Purchaser by Atlas Copco. Orders shall be subject to acceptance at Atlas Copco's principal corporate offices in Wayne, New Jersey.

2. DELIVERY. Unless otherwise stated on the face hereof, Products manufactured, assembled or warehoused in the continental United States are delivered F.O.B. shipping point, and Products shipped from outside the continental United States are delivered F.O.B. point of entry. Where the scheduled delivery of Products is delayed by Purchaser or by reason of any of the contingencies referred to in Section 5, Atlas Copco may deliver such equipment by moving it to storage for the account of and at the risk of Purchaser. Shipping dates are approximate and are based upon prompt receipt of all necessary information and approvals from Purchaser. Atlas Copco reserves the right to make delivery in installments.

3. SECURITY AND RISK OF LOSS. Upon request from Atlas Copco, Purchaser agrees to execute a security agreement covering the Products sold or other assets and to perform all acts which may be necessary to perfect and assure a security position of Atlas Copco. Notwithstanding any agreement with respect to delivery terms or payment of transportation charges, risk of loss or damage shall pass to Purchaser and delivery shall be deemed to be complete upon delivery to a private or common carrier or upon moving into storage, whichever occurs first, at the point of shipment for Products assembled, manufactured or warehoused in the continental United States or at the point of entry for Products shipped from outside the continental United States.

4. PAYMENT. If Purchaser fails to pay any invoice when due, Atlas Copco may defer deliveries under this or any other contract with Purchaser, except upon receipt of satisfactory security for or cash in payment of any such invoice. Failure on the part of Purchaser to pay invoices when due shall, at the opinion of Atlas Copco, constitute a default in addition to all other remedies Atlas Copco may have under these conditions of sale or applicable law. If in the judgment of Atlas Copco the financial condition of Purchaser at any time prior to delivery does not justify the terms of payment specified, Atlas Copco may require payment in advance or cancel any outstanding order, whereupon Atlas Copco shall be entitled to receive reasonable cancellation charges. If delivery is delayed by Purchaser, payment shall become due on the date Atlas Copco is prepared to make delivery. Should manufacture be delayed by Purchaser, pro rata payment shall become due if and to the extent required of Atlas Copco by its contracts with the manufacturer. All installment deliveries shall be separately invoiced and paid for without regard to subsequent deliveries. Delays in delivery or nonconformities in any installment shall not relieve Purchaser of its obligation to accept and pay for remaining installments.

A service charge of the lesser of one percent (1%) per month or the highest rate allowed by applicable law shall be charged on all overdue accounts.

5. FORCE MAJEURE. Atlas Copco shall not be liable for loss, damage, detention, or delay, nor be deemed to be in default from causes byond its reasonable control or from fire, strike, or other concentrated action of workmen, act or omission of any governmental authority or of Purchaser, compliance with import or export regulations, insurrection or riot, embargo, delays or shortages in transportation, or inability to obtain necessary engineering talent, labor, materials, or manufacturing failities from usual sources. In the event of delay due to any such cause the date of delivery will be postponed by such length of time as may be reasonably necessary to compensate for the delay.

6. NEW PRODUCT WARRANTY. Atlas Copco warrants to the Purchaser that the Products manufactured by Atlas Copco or its affiliates shall be free of defects in design, material and workmanship for the following periods of time:

(a) LIMNO — One year from date of installation

(b) Compressors — Covered by particular A.C.N.A. Division supplying unit. (See attached).

(c) All other equipment and accessories, except normal wear parts and consumables, three (3) months from date of shipment.

Should any failure to conform with this warranty appear prior to or after shipment of the Product to Purchaser during the specified periods under normal and proper use and provided the Product has been properly stored, installed, handled, and maintained by the Purchaser, Atlas Copco shall, if given prompt notice by Purchaser, repair or replace the nonconforming Product or authorize repair or replacement by the Purchaser and reimburse the Purchaser for reasonable expenses incurred.

Replaced Products become the property of Atlas Copco.

Atlas Copco warrants Products or Parts thereof repaired or replaced pursuant to the above warranty, under normal and proper use, storage, handling, installation and maintenance, against defects in design, workmanship and material for a period of thirty (30) days from date of start-up of such repaired or replaced Product or Parts thereof or the expiration of the original Product warranty, whichever is longer.

When the nature of the defect is such that it is appropriate in the judgment of Atlas Copco to do so, repairs will be made at the site of the Product. Repair or replacement under the applicable warranty shall be made at no charge for replacement parts, warranty labor, serviceman transportation and living costs when work is performed during normal working hours (8 a.m. to 4:30 p.m., Monday through Friday, exclusive of holidays). Labor performed at other times will be billed at the overtime rate then prevailing for services of Atlas Copco personnel.

Atlas Copco warranty does not extend to Products not manufactured by Atlas Copco or its affiliates. As to such Products or Parts, Purchaser shall be entitled to proceed only upon the terms of that particular manufacturer's warranty. Warranty does not apply to defects in materials provided by Purchaser or design stipulated by Purchaser.

THE FOREGOING WARRANTIES ARE EXCLUSIVE AND IN LIEU OF ALL OTHER WARRANTIES OF QUALITY, WRITTEN, ORAL OR IMPLIED, AND ALL OTHER WARRANTY OF MERCHANTABILITY OR FITNESS ARE HEREBY DISCLAIMED. Correction of nonconformities as provided above shall be Purchaser's exclusive remedy and shall constitute fulfillment of all liabilities of Atlas Copco (including any liability for direct, indirect, special, incidental and consequential damages) whether in warranty, strict liability, contract, tort, negligence, or otherwise with respect to the quality of or defects in the Product delivered hereunder.

7. LIMITATION OF LIABILITY. IN NO EVENT SHALL ATLAS COPCO BE LIABLE FOR SPECIAL, INDIRECT, INCIDENTAL OR CONSEQUENTIAL DAMAGES however arising whether in warranty, strict liability, contract, tort, negligence or otherwise, including but not limited to loss of profits or revenue, loss of total or partial use of the Products, facilities or services, downtime costs, or claims of Purchaser for such or other damages whether on account of Products furnished hereunder or delays in delivery thereof or of services performed upon or with respect to such Products. Atlas Copco's liability on any claim whether in warranty, strict liability, contract, tort, negligence or otherwise for any loss or damage arising out of, connected with, or resulting from this contract or the performance or breach thereof, or from the design, manufacture, sale, delivery, resale, repair, replacement, installation, technical direction of installation, inspection, servicing, operation or use of any Product covered by or furnished under this contract shall in no case (except as provided in the section entitled "Patent Indemnity") exceed the purchase price allocable to the Product or Part thereof which gives rise to the claim.

All causes of action against Atlas Copco arising out of or relating to

Effective Date: January 1, 1985

this contract or the performance hereof shall expire unless brought within one year of the time of accrual thereof.

8. PRICES. Prices to the Purchaser shall be the Atlas Copco list price in effect at time of order, less applicable discounts.

This contract applies to new Products only. Purchases of used equipment shall be on terms to be agreed upon at time of sale to Purchaser.

The price does not include any Federal, state or local property, license, privilege, sales, service, use, excise, value added, gross receipts, or other like taxes which may now or hereafter be applicable to measured by or imposed upon with respect to this transaction, the property, its purchase, sale, replacement, value, or use, of any services performed in connection therewith. Purchaser agrees to pay or reimburse Atlas Copco, its subcontractors or suppliers any such taxes which Atlas Copco, its subcontractors or suppliers are required to pay or collect or which are required to be withheld by Purchaser.

The price shall also be subject to adjustment in accordance with the published Price Adjustment Clauses, which price adjustment information shall supersede the terms of this Section 8, where inconsistent herewith.

9. INFORMATION FURNISHED PURCHASER. Any design, manufacturing drawings or other information or materials submitted to the Purchaser and not intended for dissemination by Purchaser remain the exclusive property of Atlas Copco and may not, without its consent, be copied or communicated to a third party.

10. PATENT INDEMNITY. For purposes only of this Section 8, where used, the designation "Atlas Copco" shall be deemed to mean Atlas Copco North America Inc. and its subsidiaries.

Atlas Copco shall at its own expense defend any suits or proceedings brought against Purchaser insofar as based on an allegation that Products furnished hereunder constitute an infringement of any claim of any patent of the United States of America, other than a claim covering a process performed by said Products or a product produced by said Product provided that such Products are manufactured by Atlas Copco, are not supplied according to Purchaser's detailed design, and are used as sold by Atlas Copco. Purchaser shall have made all payments then due hereunder, and Atlas Copco is notified promptly in writing and given authority, information and assistance for the defense of said suit or proceeding, and Atlas Copco shall pay all damages and costs awarded in any suit or proceeding so defended, provided that this indemnity shall not extend to any infringement based upon the combination of said Products or any portion thereof with other Products or things not furnished hereunder unless Atlas Copco is a contributory infringer. Atlas Copco shall not be responsible for any settlement of such suit or proceeding made without its written consent. If in any suit or proceeding defended hereunder any Product is held to constitute infringement, and its use is enjoyed, Atlas Copco shall, at its option and its own expense, either replace said Products with noninfringing Products, or modify it so that they become noninfringing, or remove it and refund the purchase price and the transportation and installation costs thereof. THE FOREGOING STATES THE ENTIRE LIABILITY OF ATLAS COPCO WITH RESPECT TO PATENT INFRINGEMENT.

To the extent that said Products or any portion thereof are supplied according to Purchaser's detailed design or instructions, or modified by Purchaser or combined by Purchaser with equipment or things not furnished hereunder, except to the extent that Atlas Copco is a contributory infringer, or are used by Purchaser to perform a process, or produce a product, and by reason of said design, instructions, modification, combination, performance or production, a suit or proceeding is brought against Atlas Copco, Purchaser agrees to indemnify Atlas Copco in the manner and to the extent Atlas Copco indemnifies Purchaser in this Section 10 insofar as the terms hereof are appropriate.

11. ASSIGNMENT. Any assignment of this contract, or any rights hereunder, without prior written consent of Atlas Copco by a duly authorized representative thereof shall be void.

12. CANCELLATION. Any order or contract may be cancelled by Purchaser only upon payment of reasonable charges (including an allowance for profit) based upon costs and expenses incurred, and commitments made by Atlas Copco.

13. PARTIAL INVALIDITY. If any provision herein or portion thereof shall for any reason be held invalid or unenforceable, such invalidity or unenforceability shall not affect any other provision or portion thereof, but these conditions shall be construed as if such invalid or unenforceable provision or portion thereof had never been contained herein.

14. REMEDIES. The remedies expressly provided for in these conditions shall be in addition to any other remedies which Atlas Copco may have under the Uniform Commercial Code or other applicable law.

Cure for degraded waters

Our lakes and watercourses have long been victims of pollution.

Even freshwater basins and reservoirs can be polluted through inflow water containing phosphorus and nitrogen. In addition, airborne contaminations can contribute. All these types of water may need help to recover.

The problem is often oxygen shortage. If nothing is done, the lake's condition frequently becomes worse with little or no oxygen in the bottom strata, which puts all its biological life at stake.

The hypolimnion aerator LIMNO offers an effective treatment for deep lakes which have become oxygen deficient.

LIMNO

Atlas Copco Aquatec

Oxygen – basic element of life

Oxygen is the most important single element involved in the total dynamic balance of the ecosystem. Without oxygen, no lake can survive.

In a healthy lake or reservoir, there is a balance between the oxygen supply – from the atmosphere and by photosynthesis – and the oxygen consumed in the process of decomposition and mineralisation of organic matter.

In a temperate climate, and especially in stratified lakes and reservoirs, the distribution of oxygen is highly dependent on the characteristics of the lake such as the relation between the volume of the warmer, upper layer (the epilimnion) and the cooler bottom water body (the hypolimnion).

By studying the concentration and distribution of dissolved oxygen in a lake, you get a good picture of its general health status.

The amount of oxygen consumed in the hypolimnion during a stagnation period – the oxygen deficit – provides an indirect estimate of the productivity of the lake.

A polluted lake produces an excess of organic matter due to a too rich nutrient supply. The decomposition of this matter requires more oxygen than the ecosystem may be able to provide.

If the oxygen in the hypolimnion is completely consumed, the condition becomes critical:

Fermentation processes transform both organic and inorganic matter. Methane and hydrogen sulphide are produced and inorganic nutrients such as phosphorus and nitrogen, are released and dissolved in the water and then distributed during the lake's periods of circulation. This increases the nutrient concentrations and the productivity escalates even more.

The Atlas Copco LIMNO aerator has been developed to supply oxygen to the hypolimnion without disturbing the thermal stratification. In this way a high oxygen concentration is maintained throughout the stagnation periods and the release of nutrients from the sediment is minimized.

The LIMNO aeration system

The LIMNO system is especially designed for oxygenation of stratified lakes and reservoirs.

It is very important to make a careful limnological investigation and state a definite diagnosis of the lake's condition before any LIMNO installation can be made. Only then can the adequate number, size and location of the aerators be determined.

How does it work?

The LIMNO aerator consists of two concentric tubes, covered by a dome, and interconnected by radial walls.

The outer tube has a number of outlets close to the lower end. From the dome a venting pipe connects the unit with the atmosphere.

The unit is permanently anchored to the bottom by means of concrete weights and nylon bands attached to the outer tube and the lower ring frame.

During operation and standstill the unit is held upright by the air cushion trapped in the dome top.

A compressor on the shore supplies the aerator with compressed air via a hose placed on the lake bottom.

Through the primary diffusor, placed under the intake cone, the airflow is disintegrated into fine air bubbles.

As the bubbles rise through the inner tube, an upward water flow is generated – the airlift pump principle.

During the intense contact between the air bubbles and the water, oxygen is transferred to the water.

When the water spreads over the rim of the inner tube, the flow velocity is reduced. The air then separates from the water and leaves the aerator via the venting pipe.

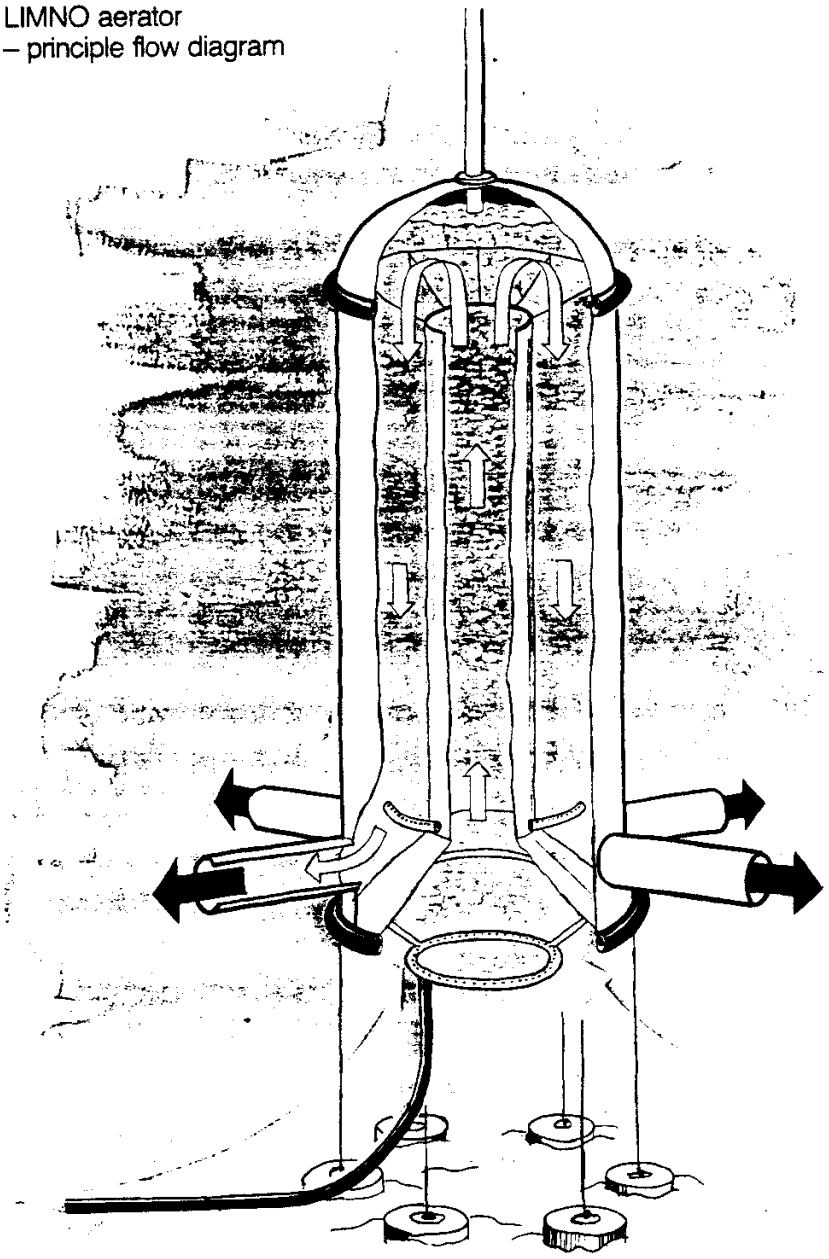
The water flow then turns downward through the space between the tubes and leaves the unit as a number of horizontal jets through the outlets and spreads in the hypolimnion.

Compressed air is also supplied to a secondary, ring-shaped air diffusor placed between the tube walls in the lower part of the unit. The air bubbles from this diffusor meet the downward water flow and in this way optimizes the aerator's oxygen transfer.

The airflow from the secondary diffusor is collected at the top of the unit and released to the atmosphere through the venting pipe, which is provided with a buoy close to the surface.

The oxygen-poor water just above the sediment is drawn towards and through the aerator becoming oxygenated and then spread horizontally through the hypolimnion. In this way, the oxygen is supplied for the required normal decomposition and mineralisation of organic sediment.

LIMNO aerator
– principle flow diagram



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Design features

The new LIMNO aerator is made of flexible material which greatly facilitates transport and installation.

All components of a LIMNO unit are of non-corrosive material, mainly plastic. The tubes, walls and top dome as well as the inlet cone and outlet arms are of PVC-coated polyester fabric.

This material meets the following standards: BS No. 3424, DIN No. 53352 and 53354, Fed-Std-5041 and 5100.

All joints are made by automatic, high-frequency welding. Reinforcement strips prevent tearing damages.

The upper and lower support ring frames are made of polyethylene and so are the venting pipe and the diffusors.

The air supply hose is of polyethylene. Depending on the diameter required it is anchored to the bottom of the lake either by a lead wire, wound around it (small diameters), or by concrete blocks secured by nylon bands.

LIMNO FABRIC DATA	Outer tube	Inner tube and radial walls
Overall weight	1 000 g/m²	670 g/m²
Warp tensile	4 400 N/50 mm	3 000 N/50 mm

Capacity range and dimensions

All LIMNO units are designed and manufactured to the customer's specifications to fit a particular project. The table gives a general idea of the capacity range within which LIMNO aerators work and their possible dimensions. Bigger units are designed on request.

		Range	Examples				
Oxygenation capacity	kg/day	100–1600	100	200	400	800	1600
	lb/day	220–3500	220	440	880	1760	3500
Air consumption (free air)	l/s	7–112	7	14	28	56	112
	cfm	15–240	15	30	60	120	240
Diameter	m	2–8.8	2.0	2.9	4.3	5.8	8.8
	ft	6.6–29	6.6	9.5	14	19	29
Height	m	5–20	15	15	15	15	15
	ft	16–66	66	66	66	66	66
Weight (excl. anchor)	kg	250–1300	250	350	600	900	1300
	lb	550–2860	550	770	1320	1980	2860
Anchoring weight (submerged)	kg	350–4500	350	500	1000	2000	4500
	lb	770–9900	770	1100	2200	4400	9900

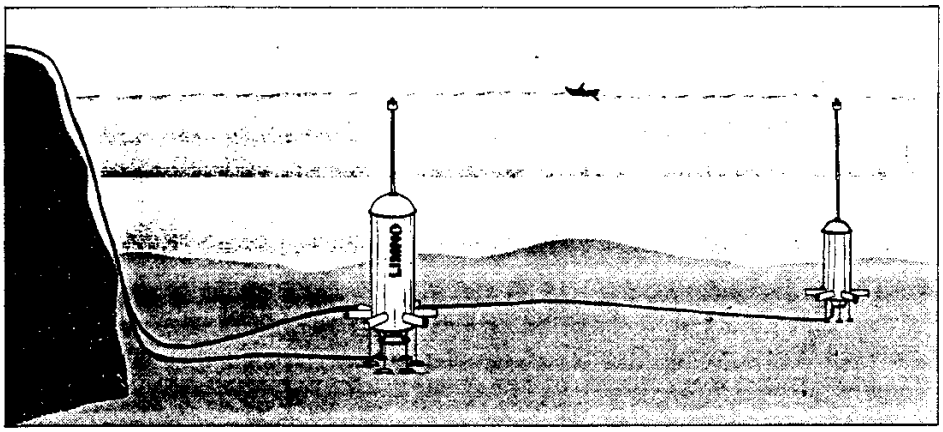
Installation

Atlas Copco offers to supervise the installation of LIMNO plants – either carried out by our own people or the customer's personnel.

The equipment is delivered to the lake shore. Of course, the LIMNO unit comes folded, packed in a box. A fork lift, or the like, is used for the unloading and for launching the bucket-shaped, concrete anchor weights into the water at a depth of about one meter, where they stay afloat. From here they can be tugged to their determined location, filled with water and sunk to the bottom.

On a suitable free space on the shore the LIMNO unit is unfolded and completed by mounting the accessories to the body. Then it is launched, tugged into position, attached to the anchors and pulled down and secured by a diving team.

The air supply line comes in a roll, either pre-loaded with lead wire, wound around it, or successively provided with concrete anchor weights as it is laid out from a raft. After connection and control, the installation is ready for immediate operation.



LIMNO gives optimum oxygen transfer efficiency

A high oxygen transfer efficiency of an aerator unit is possible to obtain by having long contact times between air and water resulting in low flow velocities. However, for low flow velocities, the oxygenation capacity, e.g. ton/day, decreases. For a given capacity demanded, the number or the size of units installed then has to be increased. Thus the investment cost increases.

So, although a high transfer efficiency results in a low running cost, it is of course the total cost that is important.

Main factors contributing to oxygenation efficiency:

1 According to Henry's law, the solubility of a gas in a liquid increases with the pressure. Thus, the deeper the LIMNO installation, the higher the hydrostatic pressure and the more oxygen can be dissolved (per unit of liquid volume). In most aeration projects LIMNO is installed just above the bottom taking maximum advantage of this law.

2 Solubility of oxygen in water is affected by the temperature and increases considerably in cold water. The LIMNO aerator runs in the cold hypolimnion and benefits from its low temperature.

3 The oxygen transfer efficiency depends on the oxygen concentration of the intake water. The more the intake water is depleted of oxygen, the better the transfer efficiency.

4 Likewise, the lower oxygen concentration required of the aerated water, the higher the efficiency.

5 The secondary air diffusor not only gives a favourable oxygen transfer due to the counterflow principle, but also makes it possible to dissolve the maximum amount of oxygen according to Henry's law.

6 Some fractions, representing the BOD and the COD portions, may be instantaneously oxidised already in the aerator unit. This fact must be included when calculating the efficiency.

7 The transfer efficiency also depends on the specific compressor efficiency. This in turn depends on the air-pressure needed and the compressor design.

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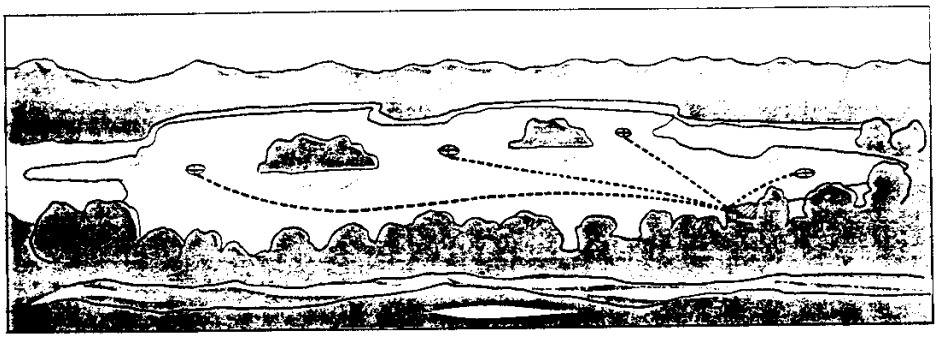


Operation

The LIMNO plant is normally started after the spring circulation period to counterbalance the increasing oxygen demand in the hypolimnion.

The LIMNO units are commonly run throughout the summer stagnation period with only a short stop around the autumn circulation, whereafter they are restarted for the winter if required. The design of the system makes it possible to run during the winter without disturbing the ice cover.

The oxygenation capacity of the LIMNO units can be matched against the varying oxygen consumption to maintain a specific oxygen concentration by reducing the airflow to the units or running a reduced number of units.

Compressed air supply and control

Compressor

The airflow to the LIMNO units is supplied by a compressor installed on land close to the shore.

The air-pressure required is the total sum of the hydrostatic pressure at the LIMNO diffusors and the pressure drops over the air supply lines.

The compressed air must be oil-free, which is why non-lubricated compressors are recommended.

For polyethylene air supply lines, a compressed air aftercooler might be required.

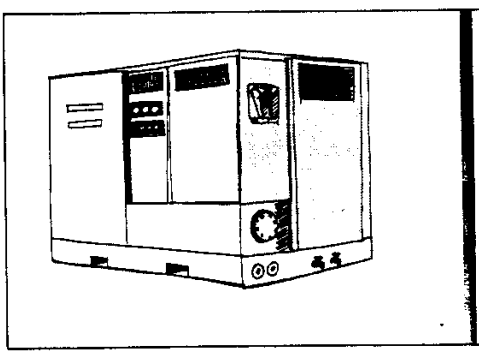
Although compressors today normally are silenced, packaged units, special considerations may have to be taken in view of the sensitive lake environment. No house is required for modern package-type compressors, but normally at least a shed is erected.

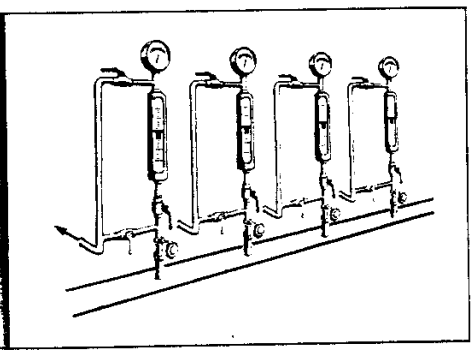
Modern screw type compressors are used for larger systems and require a minimum of service. Service contracts for the compressor installation are frequently applied.

Control

From the compressor unit, the airflow is led to a manifold to which the air supply line for each LIMNO unit is connected. There is a control system comprising an airflow meter with a precision pressure gauge, a regulating valve and a by-pass circuit for each unit.

The control system offers easy checking of the proper functioning of the LIMNO units installed out in the lake.





Results

For each lake management project, the results of hypolimnetic aeration vary with the characteristics of the ecosystem – the eutrophicated lake or the iron-manganese rich drinking-water reservoir. However, some common typical results from LIMNO projects have been summarised in the principle diagram below.

OXYGEN

When the LIMNO plant is started in a completely oxygen depleted hypolimnion, the full installed air capacity is supplied to all the LIMNO units. A rapid increase in the oxygen concentration is achieved.

When the desired oxygen concentration is reached through aeration during the stagnation period, the system can be adjusted to run with reduced capacity – just enough to maintain this concentration.

PHOSPHORUS

With the increased oxygen concentration, there is normally an immediate and steep drop in the phosphate concentration from say 0.8 to 0.05 mg/l, and at the same time the concentration of iron is rapidly reduced. This initial reduction is supposed to be caused through precipitation of ferric iron hydroxide with adsorbed phosphate. A slower decrease in the phosphate concentration, following the first rapid one, is normally depending on adsorption to the successfully oxidised sediment surface.

NITROGEN

The aeration also causes a drop in the inorganic nitrogen concentration. Typical values are from more than 2 to less than 0.3 mg/l. E.g. if the nitrogen mainly occurs as ammonium in the hypolimnion before aeration, the aeration typically brings about a rapid reduction in the concentration of ammonium and a synchronous increase in nitrate.

IRON and MANGANESE

The drop in the iron concentration has already been mentioned in connection with the phosphate reduction. The concentration of ionic iron is exceedingly low in aerated waters, most iron occurs as ferric hydroxide in particulate form.

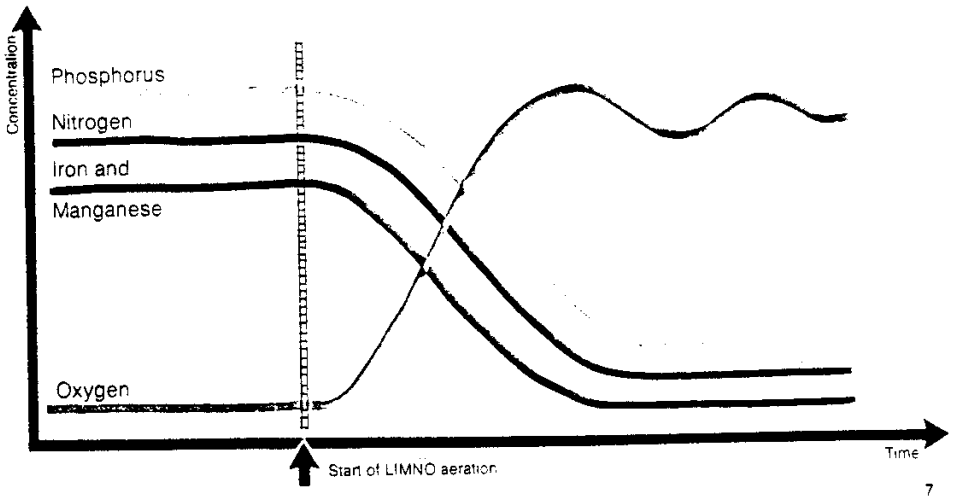
The solubility of manganese is considerably higher than that of iron, but it reacts in an analogous manner. These similarities in chemical reactivity between iron and manganese, although clear differences exist between the two metals, make them behave in a similar fashion in freshwaters. In drinking-water reservoirs where LIMNO aeration has been applied, the concentration of both metals have been almost completely suppressed improving the drinking-water quality and reducing the preparation cost.

TRANSPARENCY and CHLOROPHYLL

The normal variation of these parameters are big due to e.g. difference in meteorological and hydrological factors and irregular diffuse leakage of nutrients into the upper water layer – the epilimnion.

The effect of aeration on transparency and chlorophyll consequently has to be studied over a longer time period as it is not as immediate as on the elements above.

However, a steady reduction of chlorophyll has been recorded at many LIMNO aeration projects, and for the new installations the tendencies are positive.



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Our line of business:

Water care

We specialize in environmental programs for water management. We have the know-how and the resources to investigate and diagnose polluted lakes, watercourses, ponds and reservoirs and to design and carry out successful restoration projects.

For more than a decade now, Atlas Copco has been involved in pioneering work within the field. During this time, we have been cooperating closely with limnological experts at several universities. Today, this collaboration has become permanently established which enables us to offer our customers solutions and services that are second to none.

The Atlas Copco Group has sales companies in 46 countries and representatives in another 120.

Our program of products and processes can be divided into two main categories – restoration of polluted lakes and preventive measurements against pollution.

Lake Management

LIMNO

The LIMNO system is especially designed for oxygenation of stratified lakes and reservoirs i.e. to supply oxygen to the hypolimnion without disturbing the natural stratification.

In lakes LIMNO decreases the internal phosphorus concentration and thereby reduces the production of algae, making the lake an aesthetic and recreational asset.

In reservoirs LIMNO suppresses the release of phosphorus, iron and manganese. Thereby the drinking water quality improves, the preparation cost is lowered and the chlorination demand reduced.

Diffuse aeration/destratification

Aeration of shallow waters, e.g. waterways and canals, by releasing an airflow from submerged, perforated hoses to increase the oxygen concentration throughout the water column.

RIPLOX

Biochemical oxidation of lake sediment with nitrate. A more economic alternative than dredging that drastically reduces the oxygen demand of the sediment, thereby minimising the internal release and loading of phosphorus.

CONTRACID

Buffer injection of sodium carbonate into the sediment of acidified lakes for long-term neutralisation of acid rain and acid flow from tributaries. An attractive alternative to liming in lakes with high humus content and short retention time.

Oil Spill Control Systems

Barrier

Pneumatic barriers for oil spill containment for permanent installations at oil loading/unloading jetties and docks to prevent spreading of oil spills. No deployment work, no maintenance, always ready to work.

Skimmer

Oil spill recovery unit based on the airlift principle, designed to handle a huge flow of oil-water mixture, recovering just the oil.

Ice Prevention

Ice prevention systems for ferry routes, hydroelectric power dams, marinas and the like to facilitate operations or protect existing structures

Mixing

Different applications of the airbubble technique for mixing of density stratified flows, such as prevention of salt water intrusion into harbours, locks and estuaries, and homogenization of solids in a liquid.

Silting Prevention

Silting prevention comprises a MUD-TRAP and an airlift pump installation in harbours and locks where conventional dredging is difficult.

Atlas Copco

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Atlas Copco Aquatec

A Division of Atlas Copco North America Inc.
70 Demarest Drive, Wayne, New Jersey 07470
Telephone (201) 696-0554 Telex 219227